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OPERATIONAL FACTORS OF AIR SERVICE TO SMALL COMMUNITIES

FINAL REPORT

DECEMBER 1975

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MOFFETT FIELD, CALIFORNIA 94035

DOUGLAS AIRCRAFT COMPANY

MCDONNELL DOUGLAS CORPORATION

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PREFACE

This volume comprises the Final Report and Executive Summary of a six-month study of Operational Factors of Air Service to Small Communities performed by the Douglas Aircraft Company, McDonnell Douglas Corporation, for the NASA as an extension to Contract NAS2-8135, Analysis of Operational Requirements for Medium Density Air Transportation.

The NASA Technical Monitor for the study was Thomas L. Galloway, Aeronautical Systems Office, Ames Research Center, Moffett Field, California.

The Douglas study team consisted of J. Seif, Technical Director, assisted by M. A. Sousa, Aircraft Analysis, and S. C. Nelson, Systems Operations.

The Executive Summary for the study consists of the Preface, Introduction, and Summary of this volume.

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INTRODUCTION

Background

Current air service to small communities in the United States is provided in a variety of ways. Major trunk airlines serve small cities which remain in their route structure from the years before 1945 when the trunks were the only organized service. These small cities and communities have been retained from the early operations of the trunks because they provide a source of connecting travelers for long-haul operations. Originally, for example, many of these cities were stopping points for the DC-3 aircraft on transcontinental service. Immediately following World War II, the major trunk carriers acquired four-engined transport aircraft from military surplus. These aircraft were efficient at longer ranges with greater payloads compared with the pre-war aircraft. Thus the trunks moved to drop service to the smaller communities and concentrate on the more profitable long distance routes.

Because of this trend, the Civil Aeronautics Board (CAB) created a new class of local-service airlines in the mid-1940's. These airlines served the small communities and provided a collection network for feeder service to connect with the trunks. Many cities were transferred from trunk to local - a total of 211 from the mid-1940's to 1969. Many other cities were added to local service airlines as a result of petitions and hearings at the CAB. (Reference 1).

During the 1950's, the local service airlines upgraded their equipment and acquired larger aircraft. Service to small communities became increasingly unprofitable and pressure was generated to reduce or drop service to these communities.

With the availability of good, small aircraft, many fixed base operators and entrepeneurs developed an air taxi service to provide flexible air service to small communities and over routes with low travel demand. The adoption of Federal Regulation Part 298 in 1952 permitted air taxi operations with aircraft up to 12,500 pounds takeoff weight. In 1969, the CAB established a new class of carrier defined as commuters. These carriers provided at least five scheduled round trip flights per week or flew regular mail service.

In late 1972, the CAB raised the aircraft payload and/or weight limitations for commuter airlines to 30 passengers or 7,500 pounds payload. By 1974 there was a total of about 230 certified commuters, of which some 180 to 190 were passenger carriers only.

With the trend of the trunk and regional (local service) airlines moving toward profitable service only in the medium to high-density routes, there still remains the problem of maintaining adequate air service to the low density portion of the air travel market. This includes the traffic among small communities and between small and large communities.

In 1971, a government Civil Aviation Research and Development Policy Study (CARD) report identified the problems of providing air service to low density, short-haul markets as one of the most pressing difficulties facing the U.S. aviation industry. In response to this policy statement, the NASA has been sponsoring many technical and system studies related to the problems cited in the CARD report. The study which is reported herein investigates the potential of a 30-passenger aircraft serving the low density short-haul markets.

In the recently completed NASA study, "Analysis of Operational Requirements for Medium Density Air Transportation", Contract NAS2-8135, January 1975, turbofan and turboprop powered aircraft, ranging in passenger size from 30 to 70 seats, were evaluated in the medium density market. The traffic densities included 20 to 500 passengers per day per route for travel distances up to 800 statute miles (1287 km). The market definition included the route and traffic data from 21 commuter and nine regional airlines. Excluded from the market analysis were the routes and traffic data of the domestic trunk carriers.

Within the ground rules of that study, it was shown that a 30-passenger aircraft could provide adequate service, but needed subsidy to be profitable. The study concluded that there was a need to evaluate the requirements for an air transportation system which would integrate the commuter and the low density markets of both the local service and trunk carriers into a combined network system. This study extension investigated the potential of a 30-passenger aircraft serving the lower and middle market segments of the network defined in the original study plus the trunk carriers serving this market area.

Objectives

The stated purpose of the study was as follows:

> "The purpose of this study is to evaluate the characteristics of a 30-passenger aircraft and its scheduled operations in an expanded route structure derived from the lower and middle segments of the market previously studied."

A 30-passenger turbofan and turboprop powered aircraft were to be simulated in an airline operations and mission model to evaluate selected aircraft operational and economic factors pertinent to the operations of these aircraft in the lower density market. The major tasks of the study included the following:

- Definition and quantification of the market to be served by the 30-passenger aircraft.
- Analysis and evaluation of aircraft in terms of service and cost.
- Evaluation of fleet requirements and aircraft operational and system characteristics in terms of fleet size, itinerary planning and scheduling, economic factors, and competitive analysis.

Certain general ground rules and study guidelines were followed and consisted of the following:

Aircraft

- Payload: 30 passengers.
- Engines: Current technology on engines and propellers; fixed pitch turbofan with BPR of 6:1, FPR of 1.45:1; propeller equivalent to Lockheed Electra.
- Takeoff and Landing: Sea level, $90^{\circ}F$; FAR Part 25; balanced field length: 4,500 ft (1372 m) 15 fps (5 mps) descent rate: 3° for noise.
- Noise: FAR Part 36 less 10 EPNdB.
- Cruise Condition: Fallout (W/S and T/W for takeoff field length): 0.60 Mach minimum and 30,000 ft (9144 m) maximum.
- Stage Length: 1 x 563 n mi (1043 km) or multi-stage equivalent.
- Reserves: 100 n mi (185 km) and 45 minute hold.

Operations

- o A basic revenue yield function was based on CAB Class 7 Phase 9 fares for 1974. All costs were expressed in constant 1974 dollars. Fuel costs were 26 cents per gallon.
- o The direct operating cost (DOC) formulas applied were modified and updated from the original NASA Medium Density Study (see Appendix A-4).
- o The IOC to revenue ratio was modified from 58 percent of revenue in the Medium Density Study to 53 percent of revenue. This modification resulted from analysis of the IOC equations in the NASA Study of Short-Haul Operating Economics (NAS2-8549).
- o A minimum flight schedule for any 1985 fleet solution was required to provide at least the same flight frequencies as scheduled in 1974. A target system load factor of 60 percent was applied to basic fleet planning.
- o Net Operating Income was defined as passenger revenue less DOC and IOC for the fleet.
- o A U.S. domestic mission model was constructed consisting of the passenger data and route structure using 1974 statistics as the base for projecting revenue passenger miles and flight schedules.
- o A specific mission model of the 1974 Frontier Airlines Convair 580 and the deHavilland Twin Otter routes was also constructed for specific analyses related to operational changes which might increase the effectiveness of the 30-passenger aircraft.
- o An operational scenario was developed for airline simulation and evaluation of the best operational and economic characteristics of the 30-passenger aircraft to serve the low-medium density market.

A number of sensitivity studies were conducted in the total U.S. domestic traffic with the results measured in terms of both fleet performance and net operating income. These studies included:

- Extension of Part 298 Exemption to aircraft of seat capacity greater than 30.
- Effect of higher growth rates on the commuter market.
- Effect of reductions in maneuver time on direct operating costs.
- Effect of fare increases on net operating income.
- Effect of reduction in indirect operating costs.

In the Frontier Airlines selected network sensitivity studies were conducted and these included:

- Effect of load factor variations on fleet performance.
- Effect of variation in annual utilization on fleet performance.
- Effect of increased service on fleet performance.
- IFR versus VFR operations.

Approach

Market Definition

The data base of the original NASA Medium Density Study was expanded and reoriented in order to define the characteristics of the low-to-medium density market. A portion of the original domestic carrier passenger was retained. These data included travel distances up to 400 statute miles (643 km) and travelers in the density categories of 20 to 300 passengers per day per route. Data for the travel density category of 1 to 19 passengers per day per route were added for both trunk and regional carriers. The total 1972 market amounted to 27,051,000 passengers with the trunk share being 9,651,000 and 17,400,000 for the local service (regional) carriers establishing the data base for definition of the market for air service to small communities.

The largest daily passenger density category was the 50-99 grouping which contained 4.8 million passengers. From the standpoint of range, the largest volume of passengers, over 9 million, was in the 200 to 300 statute mile (322 to 483 km) category. This market definition included 2,640 city pairs with 1,880, or over 70 percent, in the 1 to 19 daily passenger category classification.

Operations Simulation

Two types of operational simulation models were developed for this study. The first was an aggregate U.S. domestic model consisting of selected passenger traffic for nine regional and ten domestic trunk carriers. In addition, data were included for 32 commuter air carriers operating within the continental U.S. (excluding Alaska and Hawaii) and operating aircraft with at least fifteen seats in 1974. The data was drawn from the Official Airline Guide for August 1974 to establish a base year level of revenue passenger miles, scheduled seats, and scheduled flight frequencies by airport pairs. The revenue passenger miles were projected to 1985 to provide levels of demand for passenger travel.

The second model consisted of a network of routes and projected traffic data from Frontier Airlines drawn from the U.S. domestic model. This model contained data on routes flown by the Convair 580 and the deHavilland Twin Otter aircraft and excluded those routes on which Frontier Airlines flew the B-737 aircraft in 1974. This model was constructed to provide a framework for study of sensitivity of certain operational factors applicable to a 30-passenger aircraft in simulated airline operation.

In the U.S. domestic model, growth rates for revenue passenger miles and seats scheduled were 2 percent per year for commuter traffic and 5 percent per year for regional and trunk traffic. For the Frontier Airlines network, a uniform growth rate of 5 percent per year was applied on both the CV-580 and Twin Otter routes.

Aircraft Analysis

In order to evaluate the low-medium density market, as defined, two 30-passenger conceptual aircraft, a fixed-pitch turbofan and a turboprop, were designed in conformance with ground rules taken from the original NASA medium-density study. However, the design range was reduced from 850 to 563 nautical miles (1,574 to 1,044 km) reflecting the maximum range of 400 statute miles (644 km) used in the market definition.

The turbofan engine was considered as representative of current technology, moderate turbine inlet temperature, a low noise level requiring moderate acoustic treatment, and a low development cost with little or no technical risk. The turboprop represented existing turboshaft engines and conventional propellers.

Although a tracked flap was selected in the original study , a hinged flap was used in this study because of the growth potential and a wing-fuel volume limitation associated with the tracked flap configuration.

Comparative analyses of payload, block fuel, and time as a function of range were conducted. The unrefueled multi-stage range capabilities of the turbofan and turboprop aircraft at high and low altitudes at 100 percent and 50 percent load factors were evaluated.

An airports runway length survey was performed of the 32 commuter airlines to determine if changes were required in the design field length.

A representative survey was conducted of the projected instrument flight rules (IFR) versus visual flight rules (VFR) as they related to the air traffic control (ATC) terminal environments of the 1980's. The Denver Stapleton International Airport was selected to study IFR approach methods that offered potential time and fuel savings in terminal flight operation.

Operations Analysis

Within the framework of the study ground rules, guidelines, and the market definition, a 1974 base domestic model was developed and projections made to 1985. For the base model, scheduled trips, average seat capacity, applied load factor, and revenue passenger miles were determined for the commuter airlines and for both the local and trunk carriers.

A basline evaluation of noncompetitive fleet performance was made by simulating the operations of the 30-passenger turbofan-powered study aircraft in the U.S. domestic market. The results of this evaluation established the basis for all of the sensitivity studies performed.

For the analysis conducted in the selected Frontier Airlines network, a noncompetitive base case was also established using the study aircraft in noncompetitive simulations. Similar evaluations were conducted for the 30-passenger turboprop and a 40-passenger turbofan-powered aircraft. A competitive operational simulation was made with the 30-passenger study aircraft and three contemporary aircraft. These were the Short SD3-30, the Falcon 30, and the deHavilland DHC-7. A series of competitive fleet operational simulations were made with various combinations of aircraft. The first

competitive analysis was done with the four aircraft. Another competitive evaluation was made with only the study aircraft and the Short SD3-30. In addition to the simulations conducted, fleet planning sensitivities were studied using the Douglas Airline Schedule, Planning and Evaluation Model. These studies included itinerary scheduling and effects of increased frequencies on load factor and daily utilization.

An evaluation of the study results was conducted and recommendations for future study were made.

SUMMARY

The original medium density study for the NASA used a market definition for air travel of 20 to 500 passengers per day per route and travel distance to 800 statute miles (1287 km). In 1972, Civil Aeronautics Board data showed 49,422,000 travelers in this market. Of these, the original study retained 20,238,000 travelers on some 736 city-pairs routes flown by local service airlines. Trunk carrier traffic was excluded.

For the study of air service to small communities, the original market data was expanded and further reviewed to define the potential market for a 30-passenger aircraft. Both trunk and local service carrier data were expanded to include travelers in the 1 to 19 per day route category. A revised market definition was adopted to establish the data base for this extension to the original study.

The market definition for small community service was a maximum of 300 travelers per day per route including both directions. At a 60 percent load factor and 30 seats per aircraft, this will require eight round trips per day. This level is considered as good service. Further examination of this data showed a major portion of these travelers traveled distances under 400 statute miles. This plus the 300 per day criteria defined the market for this extended study. Within this definition, local service airlines in 1972 carried about 17,400,000 passengers and the trunks carried 9,651,000 travelers. These passengers were carried over a network comprised of 2,640 city pairs (routes).

The 30-passenger turbofan aircraft used in this study extension was slightly modified from the original study aircraft. A straight wing with a hinged flap instead of a tracked flap was used to optimize structural and fuel volume conditions.

The 30-passenger turboprop configuration was a redesign from the longer range, 50 passenger of the original study and was geometrically similar to the turbofan version with the exception of wing-mounted engines. Values for wing loading and thrust-to-weight ratio were the same for each version. The operating field length of 4,500 feet (1,372 meters) was the same for both configurations. The design gross takeoff weight of the turbofan was 32,564 pounds (14,768 kg) versus 32,639 pounds (14,802 kg) for the turboprop aircraft. The operating weight empty of the turboprop was about 900 pounds (408 kg) greater than the turbofan. Extra acoustic insulation in the fuselage accounted for this. However, this amount of weight differential was offset by the nearly 800 pounds (369 kg) less fuel required by the turboprop at full-payload design range. Other pertinent characteristics of the two study aircraft are summarized in the following tabulation:

	Turboprop	Turbofan
Engine Power	2 x 3390 eshp	2 x 5920 lb
	(2 x 2528 kw)	(2 x 26,337 N)
Wing Loading	88.0 psf	88.3 psf
	(180.2 kg/m^2)	(180.8 kg/m^2)
Thrust/Weight Ratio	0.364	0.363
Operator Weight Empty	21,857 lb	20,992 lb
	(9,914 kg)	(9,522 kg)
Mission Fuel (Max)	4,782 lb	5,572 lb
	(2,169 kg)	(2,527 kg)

Each aircraft had a cruise capability of Mach 0.65 at 22,000 feet (6,706 m) and Mach 0.60 at 11,000 feet (3,353 m). Compared to the turbofan, the turboprop had less need for refueling on multistage missions at load factors under 70 percent in normal airline operations.

The 4,500 foot runway length requirement for the aircraft posed no real problem. A survey of the airports used by local service and by commuter airlines revealed that only 20 of 588 airports had runways of less than 4,500 feet (1,372 m). Of these 20, only 12 had runways under 4,000 feet (1,219 m) in length.

A general survey of the projected 1985 air traffic control (ATC) environment revealed some areas in which potential time, fuel, and cost savings could be achieved in instrument flight rules (IFR) operations. For example, a comparison of the existing IFR operation on landings at Denver with two alternate IFR operations showed a flight approach path savings of 23.5 nautical miles (43.5 km) for either of the two.

The first suggested alternate IFR installation involved installation of equipment for curved-path area navigation for terminal approach and landing. The second IFR concept involved the terminal curved path approach, distance measuring equipment with separation of aircraft by weight class in the pattern and a microwave landing system for final touchdown.

Each of these two IFR systems approached visual flight rules (VFR) in time required for terminal area maneuvers. Savings from these approach methods were estimated at about $25.00 for the 30-passenger turbofan for each IFR approach and landing including a reduction of nine minutes, and a savings of 235 pounds of fuel.

The study aircraft were evaluated in detailed operations in a simulation model derived from 1974 airline schedules. The previously described passenger density and travel distance definitions were applied to a total domestic network drawn from 10 trunk, 9 regional, and 32 commuter airlines. Traffic was forecasted for the year 1985 to provide a level of demand within the operational simulation network. All revenues and costs in the simulation were in 1974 dollar levels. The 30-passenger turbofan powered study aircraft (30TF) was simulated noncompetitively in the total model. A noncompetitive fleet of 512 aircraft were shown to be capable of serving the entire small community market as defined. At a target system load factor of 60 percent and 1974 CAB fare levels, the total fleet operated at a net operating loss of about $142 million for the study year of 1985. The service provided was 2,764,000 aircraft trips as compared to 1,091,000 in the 1974 model base year.

A competitive evaluation was conducted with a 40-passenger turbofan (40TF) aircraft from the original medium density study. The resulting fleet of 60 of the 30-passenger and 340 of the 40-passenger aircraft reduced the domestic fleet net operating loss to about $24 million dollars. The base case results are tabulated and compared with the 30TF/40TF composite case as follows:

	Fleet Size	Flights Provided (000s)	Net Operating Income ($ Million)
30TF Base	512	2,704	- 142
30TF/40TF	400	2,136	- 24

Reductions in terminal maneuver time were applied to the trunk and regional carrier portion of the base case with the following results:

Terminal Maneuver Time (Minutes)		Fleet Size	Average Block Speed (MPH)	Net Operating Income ($ Million)
12.0	(base)	466	295	- 117
8.0	(savings in ground time)	423	329	- 78
4.0	(savings in ground plus air time)	378	373	- 23

These results were based upon the assumption of reduced ground maneuver times resulting from quicker turnoffs with improved access and more strategically placed taxiways to allow shorter taxi times. Reductions in air maneuver times were assumed with dedicated runways and separation in air departure routes from general aviation and larger aircraft operations.

A 4 percent savings in indirect operations could reduce base case domestic fleet indirect operating costs (IOC) with the 30TF by about $20 million and improve the net operating income (NOI) from some $142 million net loss to a net loss of about $122 million for the 512 aircraft fleet.

A portion of the total domestic market network was selected for specific studies, including simulation of competition with contemporary aircraft. This selected network consisted of routes from Frontier Airlines flown with Twin Otter and Convair 580 aircraft. A base case was established with the 30TF aircraft in a noncompetitive operation. The 30-passenger turboprop (30TP) and the 40TF also were evaluated singly. Pertinent simulation results for these three cases are tabulated as follows:

Case	Fleet Size	Aircraft Trips (000s)	Net Operating Income ($ Million)
30TF (base)	24	142	- 5.783
30TP	24	142	- 0.005
40TF	17	109	+ 0.037

The 30TF aircraft was simulated in competition with three contemporary aircraft in the selected Frontier Airlines network. Results of the simulation are tabulated for two different combinations as follows:

CASE 1 - Competitive with 30TF, Falcon 30, DHC-7 and SD3-30

Aircraft Selected	Fleet Size	Aircraft Trips (000s)	Net Operating Income ($ Million)
30TF	16	80	- 4.666
DHC-7	8	39	- 0.435
Total	24	119	- 5.101

CASE 2 - 30TF and SD3-30

Aircraft Selected	Fleet Size	Aircraft Trips (000s)	Net Operating Income ($ Million)
30TF	23	133	- 5.796
SD3-30	2	9	+ 0.019
Total	25	142	- 5.777

A summary of these simulations is presented to illustrate the 1985 service provided compared with the level in 1974 in trips/route/week:

Fleet Composition	Fleet Size	Trips Provided 1974	1985	Annual Net Operating Income ($ Million)
30TF	24	7	15	- 5.783
30TP	24	7	15	- 0.005
40TF	17	7	14	+ 0.037
30TF/DHC-7	24	7	13	- 5.101
30TF/SD3-30	25	77	15	- 5.777

The fleet results for the 30TF were modified with various cost savings previously discussed. Results are listed as follows:

	Net Operating Income ($ Million)
Frontier Airlines Base Case	- 5.783
Shortened IFR approach applied to 1/4 of annual trips saved $885,000	- 4.898
Reduction in IOC saved $853,000	- 4.045
Reduction ground maneuver time on 1/4 of annual trips saved $518,000	- 3.527
A fare increase of 15% was applied resulting in $6,702,000 increased income	+ 3.175

The competitive fleet simulation with four aircraft was rerun at 50 percent and 70 percent load factors to evaluate operational and income effects. Results are compared with the 60 percent base case. In all cases, the solution involved choice of the 30TF and DHC-7 aircraft. Results are tabulated in the following:

Target Load Factor	Fleet Size	Annual Trips (000s)	Net Operating Income ($ Million)
50%	28	141	-10.125
60% (Base)	24	119	- 5.101
70%	21	103	- 1.612

Increases and decreases in the annual utilization rates for the aircraft were made to evaluate fleet effects. Results are compared for fleets composed of the 30TF aircraft as follows:

		Utilization		
Item	Base Case	- 20%	- 10%	+ 10%
Fleet Size	24	30	27	21
Annual Hours Flown/Aircraft	2,723	2,178	2,451	2,995

The load factor, total annual trips, income and operating costs were unaffected, thus net income was constant for all cases presented.

The selected Frontier Airlines network provided a base for a detailed schedule planned for 1985 traffic levels. A basic route itinerary was planned with the 30TF study aircraft. A total of 54 airport-pair route segments were scheduled with one to eight round trips per day, equivalent to the actual April 1975 schedule for Frontier Airlines. A second or modified itinerary was planned with at least two round trips per day per segment. Results of these schedules are summarized below:

Itinerary	Fleet Size	Aircraft Departures per week	System Load Factor (%)
Basic	25	1,932	60
Modified	31	2,394	48

Additional aircraft were scheduled to increase flight frequencies with results as follows:

Fleet Size	Daily Utilization (Hours)	System Load Factor (%)
32	7.0	46
34	6.5	44
37	6.0	41

The basic growth rate in the commuter section of the domestic market was assumed at 2 percent per year. Effects of growth rates up to 12 percent per year were evaluated. A sixfold increase in growth of traffic showed a need for increased fleet size from 46 to 79 to serve commuter routes. Annual aircraft trips increased from 302,000 to 504,000. Of prime significance was an increase in system average load factor from 37.2 to 59.1 percent. However, the fleet generated a net operating loss of $16.4 million on revenues of $144.6 million, even with the benefit of higher load factors.

Within the scope, ground rules and guidelines of this study, the following conclusions and recommendations are presented.

CONCLUSIONS AND RECOMMENTDATIONS

CONCLUSIONS

The significant conclusions resulting from the analysis performed in this study are derived based on the market definition, the aircraft performance and economic ground rules, the operational simulations, and sensitivity studies conducted. These conclusions are summarized as follows:

OPERATIONS

- o An estimated 40 million air travelers comprise the projected 1985 market bounded by travel distances up to 400 miles (644 km) and 300 passengers per day per route.
- o Based on the study guidelines, a noncompetitive fleet of 512 30-passenger aircraft would be required to serve the selected lower density U.S. domestic market in 1985.
- o The cost of operations of a new 30-passenger turbofan powered aircraft exceeds potential revenue in the market studied.
- o The 30-passenger turboprop powered aircraft with the same performance characteristics as the 30-passenger turbofan aircraft achieved savings of about 21 percent in direct operating costs for the entire fleet.
- o The 40-passenger turbofan powered aircraft is more economical in competition with the 30-passenger turbofan powered aircraft assuming payload exemptions under FAR Part 298.
- o Competitive evaluation in a selected Frontier Airline network of the 30-passenger turbofan with the SD3-30, Falcon 30, and DHC-7 shows a market split between the 30TF and the DHC-7, but at an operating loss.
- o The development of high speed runway exits or multiple turnoffs with taxi-ways would be a method to reduce maneuver time since potential reductions in maneuver times show positive cost savings.

- o Savings in indirect operating costs showed only a small potential in airline operations.

AIRCRAFT

- o The 30-passenger turbofan and turboprop powered aircraft can be designed with current aerodynamic and structural technology. However, because efficient turbofan engines of the proper size are unavailable, the use of off-the-shelf engines would increase mission fuel, size and weight.
- o The 30-passenger turbofan and turboprop powered aircraft can both be designed as low-wing configurations with gross weights of 33,000 pounds performing at Mach 0.65 and up to 375 knots maximum block speed with ample operational capability to serve the study market.
- o The turboprop consumed less fuel and achieved greater single and multi-stage capability than the turbofan at comparable speed, altitude, range and payload and had 20 to 30 percent greater range at load factors below 70 percent at maximum fuel capacity.

AIR TRAFFIC CONTROL

- o Area navigation used enroute and in the terminal area would reduce the air service flight time and distances.
- o Deployment of the microwave landing system in the 1980's would permit multipath curved approaches to the runway with reductions in time and distances compared with current typical IFR operations.

RECOMMENDATIONS

Based on the results of this study as well as the knowledge gained from the original study, specific recommendations for further work are presented.

SYSTEMS AND OPERATIONS

1. Define and forecast the market and system for air service to small communities in terms of total potential passengers at distances up to 400 miles for the decade 1980-1990.
2. Determine the optimum economic and performance requirements for aircraft configurations proposed for service to small communities, utilizing best available technology.
3. Evaluate requirements for stretch/shrink aircraft capabilities in response to projected needs for two aircraft sizes.
4. Determine improvements that can be made in air service using alternate enroute and terminal area routes to achieve better use of existing navaids.
5. Determine ground maneuver time savings by improved landing procedures and the use of high speed exits (or multiple turnoffs) and taxiways.
6. Study the impact of the 1980 ATC systems such as MLS, DABS, data link, and LORAN on the operations and cost of providing air service to small communities.

REGULATORY

1. Revise Part 298 of the federal regulations code to increase the operation exemption limit to aircraft with capacity of at least 40 passengers.
2. Revise federal regulatory policy to permit greater flexibility in establishing fare structures suitable for air service to small communities.

3. Detail the institutional and regulatory changes needed to develop and implement an air transportation system to serve small communities.

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SYMBOLS AND ABBREVIATIONS

AF	Activity Factor
AR	Aspect Ratio
ARR	Arrival
ATC	Air Traffic Control
BL	Blade
BPR	Bypass Ratio
B-737	Boeing Model 737
CAB	Civil Aeronautics Board
CARD	Civil Aviation Research and Development Policy Study
C_L	Lift Coefficient - lift/qS_W
C_{L_i}	Propeller Integrated Lift Coefficient
cm	Centimeter
CONT	Controls
Cp	Power Coefficient
Cpo	Power Coefficient Static
C_{To}	Thrust Coefficient Static
IFR	Instrument Flight Rules
ILS	Instrument Landing System
in	Inch
IOC	Indirect Operating Cost
J	Advance Ratio
kg	Kilogram
km	Kilometer
kn	Knots
kw	Kilowatts

SYMBOLS AND ABBREVIATIONS (Continued)

LF	Load Factor
lb	Pound
LORAN	Long Range Navigation
m	Meter
max	Maximum
DEP	Departure
Dia	Diameter
DME	Distance Measuring Equipment
DOC	Direct Operating Cost
EPNdB	Effective Perceived Noise Level in Decibels
ESHP	Equivalent Shaft Horsepower
F	Thrust Force; Fahrenheit
FAA	Federal Aviation Administration
FAR	Federal Air Regulations
FL	Field Length
FLT	Flight
FPR	Fan Pressure Ratio
fps	Feet Per Second
ft	Feet
GJT	Grand Junction
hgt	Height
HP	Horsepower
Hr	Hour
HYD	Hydromechanic
min	Minute, minimum

SYMBOLS AND ABBREVIATIONS (Continued)

Mill	Million
MLS	Microwave Landing System
mps	Meters Per Second
MTN	Mountain
N	Newton
NASA	National Aeronautics and Space Administration
n mi, nm, N MI	Nautical mile
NOI	Net Operating Income
OAG	Official Airline Guide
OEW, OWE	Operator's Empty Weight
p	Per
PNEU	Pneumatic
Psgr	Passenger(s)
R	Ratio
RNAV	Area Navigation
RWY	Runway
RPM	Revenue Passenger Miles
s (sec)	Second
S_w	Wing Area
SHP_o	Shaft Horsepower Static
st mi (ST MI)	Statute Miles
STAR	Standard Terminal Arrival Route
TF	Turbofan
TOC	Total Operating Cost

TOFL	Takeoff Field Length
TOGW	Takeoff Gross Weight
TMB	Timberline
TP	Turboprop
T/W	Thrust-to-weight Ratio
U.S.	United States
VFR	Visual Flight Rules
VOR	VHF omni Range
W/S	Wing Loading
wt	Weight

1.0 OPERATIONAL SCENARIO

The operational scenario for this study included two types of traffic demand and mission models. The first was a total U.S. domestic mission model consisting of low-density route networks and passenger forecasted traffic for nine regional certificated air carriers plus low-density traffic from trunk carrier operations. In addition, routes and passenger data were included for 32 regularly scheduled commuter airlines. These commuter airlines were those which provided at least 10,000 seat miles (16,090 seat kilometers) of scheduled capability per day and operated aircraft with at least 15 seats in calendar year 1974.

The second mission model was composed of Frontier Airlines' network of routes with passenger data as flown by the Convair 580 50-seat turboprop aircraft and the deHavilland Twin Otter 19-seat turboprop aircraft.

Each demand model contained a base year level of revenue passenger miles projected with selected growth rates to the year 1985.

The operations scenario included a definition of the market in terms of numbers of travelers per day and distances traveled. Civil Aeronautics Board data from 1972 was used to develop and quantify this definition.

The market definition then was applied to scheduled data as contained in the Official Airlines Guide (OAG) and a simulation demand and traffic model created. Evaluation of a 30-passenger study aircraft was accomplished by simulated operation of the aircraft with a computerized simulation program. This program contained the demand model in the form of a network of routes, a basic schedule of flight frequencies, operational rules

and constraints, and performance descriptors of selected aircraft. The simulation was used in evaluation of the fleet performance of the study aircraft both noncompetitively and competitively with several contemporary aircraft considered. Results of the simulation were typically expressed as number of aircraft in the fleet with annual operational and economic performance data for the year 1985.

In addition to evaluation of the 30-passenger aircraft in both turbofan and turboprop versions, a 40-passenger turbofan aircraft from the original medium density study was included in the operational simulations. The 30-passenger turbofan also was evaluated against two turboprop and one turbofan contemporary aircraft. These were the DHC-7, the SD-3-30, and the Falcon 30.

Operational sensitivity studies were conducted in both the total domestic market simulation model and in the model based on a selected Frontier Airlines network.

1.1 Market Definition

The United States (U.S.) domestic air traffic data base used in the recently completed NASA Medium Density Study (Ref. 2) was expanded in order to add the characteristics of the low-to-medium-density air travel market. Civil Aeronautics Board (CAB) On-Line origin and destination traffic statistics for calendar year 1972 were utilized for this purpose (CAB Data Bank 4). The data includes passenger and passenger-mile statistics for all on-line flight segments (segments on which the same carrier serves all continuous coupon segments).

Traffic statistics were collected for both the U.S. domestic trunk airlines and the fifteen regional carriers operating in 1972. The traffic

base for the original NASA Medium Density Study was constructed based on the following criteria: city pairs, served by trunk or regional carriers, were included in the medium density traffic base if they generated 20 passengers per day at the low end and no more than 500 passengers per day at the high end of the market at ranges from 1 to 800 statute miles (1-1,287 km). These criteria produced a total medium density market of 49.4 million persons traveling over a network of 1,354 city pairs. This was divided into trunk carriers at 29.2 and local service or regional carriers at 20.2 million passengers, respectively, as shown in Table 1-1. Trunk carrier statistics were excluded from the initial Medium Density Study completed in early 1975.

The data base of the original study was expanded and reoriented for the study of 30-passenger aircraft service to small communities in order to define the characteristics of the low-to-medium density market. The distribution of these passengers by range and density as shown in Table 1-1 was derived from 1972 CAB statistics on Origin and Destination Air Passengers.

For the extended study of air service to small communities a portion of the original domestic carrier passenger data was retained. These data included travel distances up to 400 statute miles (644 km) and travelers in the density categories of 20 to 300 passengers per day per route. Data in the daily travel density category of 1 to 19 were added for both trunk and regional carriers as shown in Table 1-1. Passengers carried in 1972 totaled 9,651,000 for the trunk and 17,400,000 for the local service (regional) carriers within the definition of the market.

The small community market definition of 400 statute miles (644 km) trip distance included about 61 percent of the original data on domestic carriers. This is about 30 million of the original 49 million travelers.

TABLE 1-1

ORIGINAL MEDIUM-DENSITY MARKET
(STUDY MARKET INCLUDED 20,238,000)
1972

TRUNK CARRIER SHARE OF TOTAL MARKET

RANGE (ST MI)	20 49	50 99	100 149	150 199	200 249	250 299	300 349	350 399	400 449	450 500	TOTAL
	DAILY PASSENGERS CATEGORIES — PASSENGER CARRIED (THOUSANDS)										
0 99	76	146	107	66	0	0	318	132	157	344	
100 199	192	44	315	691	721	200	0	819	0	347	3,329
200 299	223	169	84	490	591	1,075	697	689	323	343	4,684
300 399	385	363	745	623	416	777	756	261	3	172	4,501
400 499	316	462	589	867	383	473	202	417	454	179	4,342
500 599	524	560	143	635	485	505	359	142	480	339	4,172
600 699	399	688	573	869	2	201	357	564	307	167	4,127
700 799	428	577	441	317	0	201	242	137	0	340	2,683
TOTAL	2 643	3 009	2 997	4 558	2 598	3 432	2,931	3 161	1,724	2 231	29,184

NOTE THESE DATA EXCLUDED FROM MEDIUM-DENSITY STUDY

REGIONAL CARRIER SHARE OF TOTAL MARKET

RANGE (ST MI)	20-49	50 99	100 149	150 199	200 249	250 299	300 349	350 399	400-449	450 500	TOTAL
	DAILY PASSENGERS CATEGORIES — PASSENGERS CARRIED (THOUSANDS)										
0 99	424	302	364	246	0	202	0	0	0	0	1,538
100 199	1 095	1 564	828	696	664	509	608	0	310	349	6,623
200 299	1 083	1 407	848	1,040	581	188	358	0	0	0	5,505
300 399	617	803	489	193	245	306	0	0	316	0	2,969
400-499	494	464	232	242	158	0	0	0	0	0	1,590
500 599	328	269	137	120	0	0	0	0	0	0	854
600 699	246	202	214	73	78	0	0	0	0	0	813
700 799	180	26	54	0	86	0	0	0	0	0	346
TOTAL	4 467	5 037	3,166	2 610	1,812	1 205	966	0	626	349	20,238

NOTE THESE DATA USED IN MEDIUM-DENSITY STUDY

AIR SERVICE TO SMALL COMMUNITIES MARKET
(STUDY MARKET INCLUDED 27,051,000)
1972

TRUNK CARRIER SHARE OF TOTAL MARKET

RANGE (ST MI)	1 19	20-49	50-99	100 149	150 199	200 249	250 299	TOTAL
	DAILY PASSENGERS CATEGORIES — PASSENGERS CARRIED (THOUSANDS)							
0 99	115	76	146	107	66	0	0	510
100 199	259	192	44	315	691	721	200	2,422
200 299	342	223	169	84	490	591	1,075	2,974
300 399	436	385	363	745	623	416	777	3,745
TOTAL	1,152	876	722	1,251	1,870	1,728	2,052	9,651

BOTH INCLUDED IN STUDY MARKET

REGIONAL CARRIER SHARE OF TOTAL MARKET

RANGE (ST MI)	1 19	20-49	50 99	100 149	150 199	200 249	250-299	TOTAL
	DAILY PASSENGERS CATEGORIES — PASSENGERS CARRIED (THOUSANDS)							
0 99	279	424	302	364	246	0	94	1,709
100 199	737	1,095	1,564	828	696	664	509	6,093
200 299	955	1,083	1,407	848	1,040	581	296	6,210
300 399	735	617	803	489	193	245	306	3,388
TOTAL	2,706	3,219	4,076	2,629	2,175	1,490	1,205	17,400

PASSENGER DATA BASE

Note in Table 1-1 that very little local service or regional carrier traffic is beyond 400 statute miles. The definition of 300 travelers per day per route is 109,500 per year per route. At a 60 percent assumed load factor for a 30-seat aircraft, this number of travelers would require an average of about 8.33 round trips per day per route. This appeared to be a reasonable upper limit to frequency of service. The addition of CAB data in the daily passenger category of 1 to 19 passengers per day per route completed the data base for definition of the market for air service to small communities.

Table 1-2 contains the number of annual passengers in the low-to-medium density market using the range and density criteria established above. This market totals over 27 million persons or well over half of the original study market. The largest daily passenger density category is the 50 to 99 grouping which contains 4.8 million passengers. From the standpoint of range, the largest volume of passengers, over 9 million, fall into the 200 to 300 statute mile bracket (322 to 483 km). The data contained in Table 1-3 indicates that the final low-to-medium density market generated 6.2 billion passenger miles (9.98 billion passenger km) in 1972. Almost 40 percent of these passenger miles were generated in the 300 to 400 statute mile range category (483 to 644 km).

Table 1-4 contains the distribution of city pairs for the low-to-medium density market. Of the 2,640 city pairs in this market sector, 1,880, or over 70 percent of these city pairs, are in the 1 to 19 daily passenger category classification.

For this study, the assumption was made that a 30-passenger aircraft would be needed for service to small communities in 1985. That part of the

TABLE 1-2

ANNUAL PASSENGERS
LOW/MEDIUM DENSITY MARKET
CERTIFICATED CARRIERS
1972

Range (St.Mi.)	Daily Passenger Category: 1-19	20-49	50-99	100-149	150-199	200-249	250-299	Total (000)
	Passengers Carried (000)							
0-99	394	500	448	471	312	0	202	2,327
100-199	996	1,287	1,608	1,143	1,387	1,385	709	8,515
200-299	1,297	1,306	1,576	932	1,530	1,172	1,263	9,076
300-399	1,171	1,002	1,166	1,234	816	661	1,083	7,133
Total	3,858	4,095	4,798	3,780	4,045	3,218	3,257	27,051

TABLE 1-3

ANNUAL PASSENGER MILES
LOW/MEDIUM DENSITY MARKET
CERTIFICATED CARRIERS
1972

Range (St.Mi.)	Daily Passenger Category: 1-19	20-49	50-99	100-149	150-199	200-249	250-299	Total
	Passenger Miles (Millions)							
0-99	28	36	33	34	28	0	7	166
100-199	152	190	248	183	203	208	104	1,288
200-299	322	329	390	224	390	293	333	2,281
300-399	406	349	402	422	291	223	369	2,462
Total	908	904	1,073	863	912	724	813	6,197

TABLE 1-4

DISTRIBUTION OF CITY PAIRS
LOW/MEDIUM DENSITY MARKET
CERTIFICATED CARRIERS
1972

Range (St.Mi.)	Daily Passenger Category: 1-19	20-49	50-99	100-149	150-199	200-249	250-299	Total
	City Pairs							
0-99	196	42	17	11	5	0	1	272
100-199	485	111	64	25	22	17	7	731
200-299	637	109	61	21	25	14	14	881
300-399	562	90	45	27	13	8	11	756
TOTAL	1,880	352	187	84	65	39	33	2,640

market which could be served with such an aircraft is partly commuter plus the low density fractions of the regional and trunk airlines. Dimensionally, the market is summarized as follows:

Daily Passengers	-	Up to 300 per day per route
Distance	-	Up to 400 statute miles (644 km)
Frequency	-	At least the same level as scheduled in 1974

1.2 Network Characteristics and Demand Models

The operational scenario for this study included two types of operational simulation models. The first was an aggregate U.S. domestic model consisting of selected passenger traffic for nine regional and ten domestic trunk carriers. In addition, data were included for 32 of the commuter air carriers operating within the continental U.S. (excluding Alaska and Hawaii).

The second model was composed of routes and projected traffic data from one regional airline drawn from the aggregate model. This model contained data on routes flown by Convair 580 and deHavilland Twin Otter aircraft. It was specifically chosen to provide a framework for study of the sensitivity of operational factors applicable to a 30-passenger aircraft in simulated airline operations.

The first of these operational simulation models contained a base year level of revenue passenger miles (RPM), scheduled seats, and scheduled flight frequencies by airport pairs. The data was drawn from the Official Airlines Guide (R. H. Donnelly Corp.) for August 1974 and annualized to represent the total year. The RPM was projected to 1985 to provide levels of demand for passenger travel.

The second model was derived from routes of Frontier Airlines based in Denver, Colorado, and excluded those on which Frontier Airlines flew the B-737 aircraft in 1974. These were considered as exceeding the travelers-per-day limit established to define the market.

1.2.1 U.S. Domestic Model and Network

The domestic model was an aggregated model containing airline and traffic statistics organized as indicated in Table 1-5.

TABLE 1-5

TRAFFIC MODEL CHARACTERISTICS

Airline Sources:		
Local Service (Regionals)	9	
Trunk Airlines	10	
Commuter Airlines	32	
Network and Traffic Data:	1974	
Round Trips Per Day	2,990	(actual)
Scheduled Seats Per Day	135,402	
Average Seats Per Trip	22.7	
Seat Miles Per Day	20,381,090	
Number of Airports	1,454	

This model was constructed by interrogation and processing of a data tape derived from the August 1974 OAG. The base data was sorted and processed by airline and equipment codes. Details of the sorting and processing of data are included in Appendix A-1, "Ground Rules for Derivation of Low-Density Traffic Model".

1.2.2 Frontier Airlines Network and Traffic Model

The second traffic model was extracted from the total domestic airline network model. It contained the forecasted 1985 demand level in revenue passenger miles for the Frontier Airlines routes included in the total model. These same routes from the Frontier Airlines network were used for a detailed itinerary planning and scheduling of the 30-passenger study aircraft. The same density of 1 to 300 travelers per day and trip distance limits of 1 to 400 statute miles (1-644 km) were used.

1.3 Operation Simulation Techniques

The evaluation of the 30-passenger study aircraft and operational factors was conducted with mathematical simulation techniques. A Douglas computerized program was used with the U.S. domestic model and with the selected Frontier Airlines network and traffic model. In these simulations, the characteristics of study aircraft, range, speed, passenger capacity and load factor desired, mathematically were matched against travel demand as expressed in the traffic model. A complex algorithm was used to derive an aircraft fleet which satisfied the demand. The process is described more extensively in Reference 2.

The study aircraft was used in the Convair 580/Twin Otter Frontier Airlines network to demonstrate a fleet operational schedule. A simulation technique was used which is called ASPEM, Airline Schedule, Planning and Evaluation Model. This model incorporates an iterative process which starts with a demand pattern of origin and destination travelers. A trial itinerary and schedule is assumed with the study aircraft. The computer generates traffic statistics and operational results such as number of operations,

people carried over the various routes, and load factors achieved. Successive iterations with changes input by a scheduler result in new solutions. Through repetitions, a schedule is selected which satisfies predetermined criteria. Results are generated to describe the schedule and fleet operations.

1.3.1 Traffic Model - Total U.S. Domestic Model

The basic traffic input for the domestic model contained data from domestic airlines. These data included revenue passenger mile demand on 1,454 airport-pair routes. To facilitate computational procedure, these data were aggregated into 262 statistical class elements. These elements contained passenger and schedule statistics. The elements were organized by range class at 50 statute miles (80 km) increments from 0-50 to 350-400 statute miles (563-644 km). They also were organized into four service classes. These consisted of hub and non-hub airport commuter carrier traffic data and regional plus trunk carrier hub and non-hub data.

In the simulation of airline operations, certain rules and assumptions were applied as follows:

- Growth rates for RPM and seats scheduled in the domestic model were 2 percent per year for commuter traffic and 5 percent per year for regional and trunk traffic.
- A minimum flight frequency for 1985 was at least equal to the 1974 schedule. No maximum restriction was imposed in the traffic model.
- The NASA Short-Haul Operating Economics Study (Reference 3) presented an IOC formula for typical fleet operations on an annual basis. This formula was applied to a typical fleet of 30-passenger aircraft as used in the basic medium density study. The resultant IOC was

53 percent of fleet revenue. This ratio was adopted for this study. It contrasts with an IOC of 58 percent of revenue recommended by the airline participants for use in the NASA Medium Density Study.

- All costs were expressed in constant 1974 dollars.
- Fuel costs were set at 26 cents per gallon. This was equivalent to the average cost in late 1974 for local service airlines.
- A target system load factor of 60 percent was used for the study aircraft.

1.3.2 Traffic Model - Selected Frontier Airlines Network

The same operational simulation technique as used in the total U.S. domestic model was applied in the selected Frontier Airlines network model. The simulation aggregated the data from 87 airport pairs into 15 statistical classes or elements. These were then divided into 50 statute mile (80 km) incremental range classes. Each element contained RPM data projected to 1985 from the 1974 schedule of service. Also included were data on trips per day at 1974 levels and the average range in each range class element. A uniform growth rate of 5 percent per year was applied to all RPM on both the CV-580 and Twin Otter routes. Other rules and assumptions for the model of the selected Frontier Airlines network operational simulation were the same as in the total domestic model.

1.3.3 Scheduling Model - Convair 580/Twin Otter Network

The simulation technique applied on selected routes from the Frontier Airlines network was used manually to develop and select an appropriate fleet size, a balanced schedule, and an itinerary for aircraft. In this simulation, a schedule was developed in which the aircraft completed the required schedule and returned to the original base at the end of each day. No repositioning of aircraft was needed to balance the schedule.

2.0 AIRCRAFT ANALYSIS

2.1 Ground Rules

In order to evaluate the low-density market, two 30-passenger conceptual aircraft, a fixed-pitch turbofan and a turboprop, were designed in conformance with ground rules taken from the NASA Medium Density Study (see Table 2-1, covering field length, noise, cruise condition, stage length and reserves). A study of the low density routes and airports showed that a 4,500 foot (1,372 m) field length was satisfactory. However, the design range was reduced from 850 to 563 nautical miles (1,574 to 1,044 km) reflecting the maximum range of 400 statute miles (644 km) used in the market definition.

The turbofan engine was considered as representative of modern turbofans with current technology, moderate turbine inlet temperature, a low noise level requiring only moderate acoustic treatment and a low development cost with little or no technical risk.

The turboprop installation represented turboshaft engines that have existed for a decade and conventional propellers with characteristics very similar to those used on the Electra aircraft.

The aircraft were designed for field length, sized for stage length and payload, with the cruise condition being a fall-out of the wing loading and thrust-to-weight ratio for the field length.

The mission consisted of either a single stage or multiple stages of equal length performed without refueling. Each stage included: takeoff allowance; climb to cruise; constant altitude cruise at near maximum speed; 300 fpm (91 mpm) cabin pressurization rate limited descent; and landing

TABLE 2-1

AIRCRAFT ANALYSIS GROUND RULES

PAYLOAD:	30 PSGR
ENGINES:	CURRENT TECHNOLOGY FIXED PITCH TURBOFAN: BPR/FPR-6/1.45 TURBOSHAFT-PROPELLER:
TAKEOFF AND LANDING	MAX TOGW-MAX LANDING WT SEA LEVEL, 90°F; FAR PART 25 BALANCED FIELD LENGTH: 4500 FT (1372 M) 15 FPS DESCENT RATE: 3° FOR NOISE (5 MPS)
NOISE:	FAR PART 36 LESS 10 EPNdB
CRUISE CONDITION:	FALLOUT (W/S AND T/W FOR TOFL): 0.60 MACH (MIN) AND 30,000 FT (MAX) (9144 M)
STAGE LENGTH:	1 x 563 N MI (OR MULTI-STAGE EQUIVALENT) (1043 KM)
RESERVES:	100 N MI AND 45-MIN HOLD (185 KM)

allowance. The reserve fuel contained sufficient fuel to climb, cruise and descend 100 nautical miles (185 km) to an alternate airport, followed by holding at maximum endurance at cruise altitude for 0.75 hours. Performance was based on standard day conditions.

2.2 Configuration

2.2.1 Turbofan

This configuration, Figure 2-1, has twin aft-fuselage-mounted engines, an arrangement which provides an aerodynamically efficient wing, low drag, blanketing of engine noise by the wing on landing approach, reduction of inlet duct ingestion, facilitation of landing gear retraction, minimum fuselage cross-section, and crash landing and ditching safety. Wing-mounted engines would provide greater stretch-shrink flexibility for the family concept. Weight and drag differences between wing-mounted and fuselage-mounted engine configurations are too small to affect the conclusions in this study.

The engine size requirement can be satisfied by derivatives of a few existing engines. However, some improvemement in fuel consumption will be required in certain cases to achieve fuel fractions matching current or near-future technology.

2.2.2 Turboprop

The turboprop aircraft, Figure 2-2, is a twin-engine, low wing configuration. The wing aspect ratio is 10.5 instead of 9.0 because of one-engine-out control considerations and the spanwise-location of the propeller. The high-lift system and the passenger cabin configuration are similar to that of the turbofan aircraft. The tail arrangement is conventional.

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CHARACTERISTIC DATA			
ITEM	WING	HORIZONTAL STABILIZER	VERTICAL STABILIZER
AREA FT.²	368.8	98.4	84.9
ASPECT RATIO	9.0	5.0	.80
TAPER RATIO	.30	.35	.80
SWEEP	5°10'	6°45'	43°30'
DIHEDRAL	5°	0°	~
T/C	YC-15	DC-9	DC-9
TAIL VOLUME	~	1.108	.091

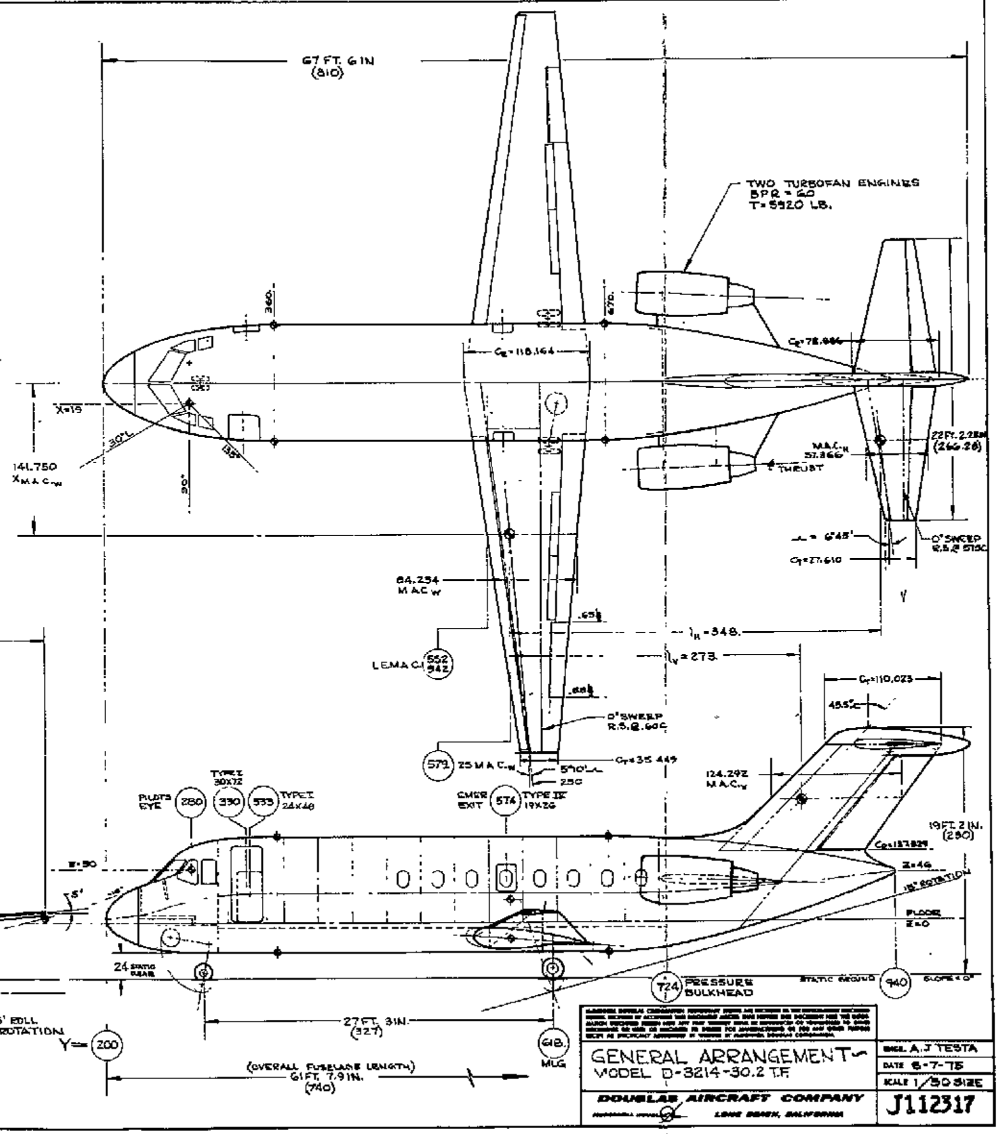
FOR FUSELAGE GEOMETRY AND CROSS-SECTION, SEE J112317 SHT. 2

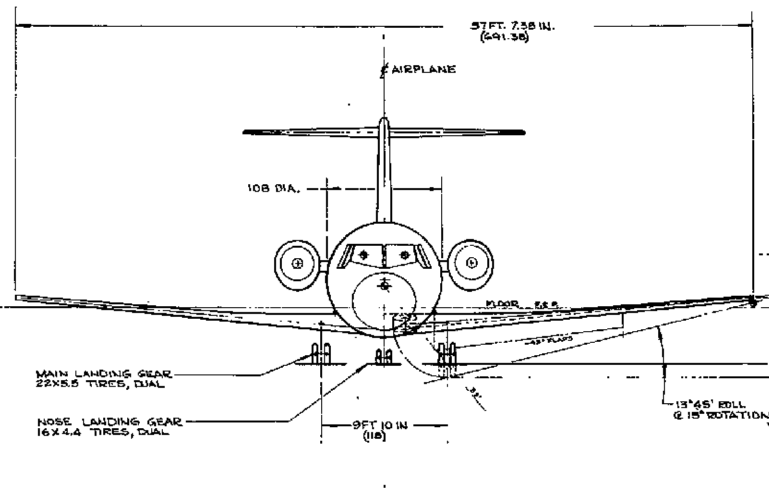
PAYLOAD CAPACITY ~

ALL-ECONOMY CLASS = 4 ABREAST @ 32 IN. PITCH = 30 SEATS

CARGO VOLUME,

CARRY-ON BAGGAGE, 5 FT.³/PAX (40 LBS./PAX @ 8 LBS./FT.³) = 150 FT.³





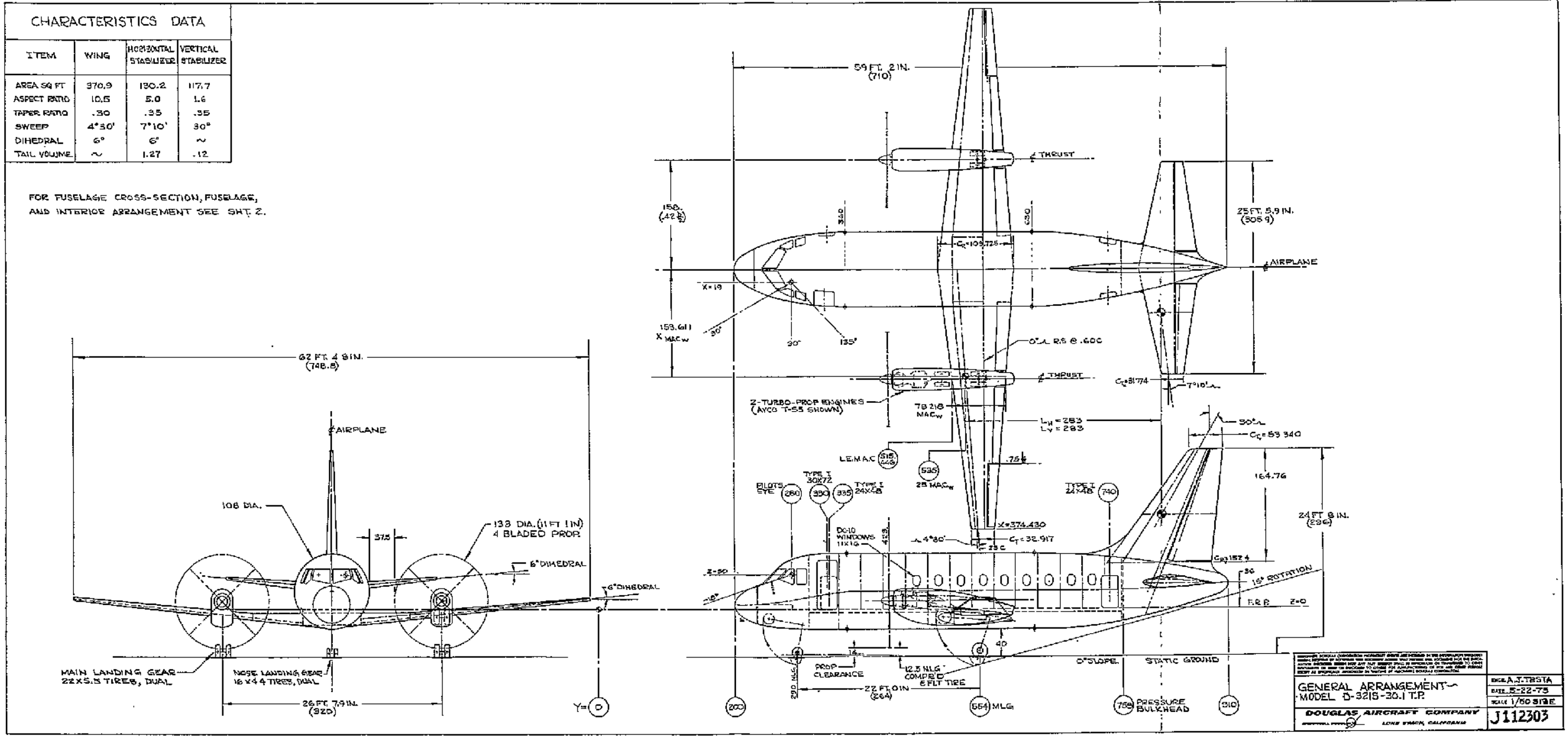
TURBOFAN: THREE VIEW

FIGURE 2-1

CHARACTERISTICS DATA

ITEM	WING	HORIZONTAL STABILIZER	VERTICAL STABILIZER
AREA SQ FT	370.9	130.2	117.7
ASPECT RATIO	10.5	5.0	1.6
TAPER RATIO	.30	.35	.35
SWEEP	4°30'	7°10'	30°
DIHEDRAL	6°	6°	~
TAIL VOLUME	~	1.27	.12

FOR FUSELAGE CROSS-SECTION, FUSELAGE, AND INTERIOR ARRANGEMENT SEE SHT. 2.



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TURBOPROP: THREE VIEW

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FIGURE 2-2

Passenger comfort was assured by exceeding or meeting the propeller design provisions on the Electra aircraft. The propeller-to-fuselage clearance is 28 percent of the propeller diameter, which exceeds the Electra value by 3 percent; the static rotational tip speed of the propeller is 720 fps (219 mps), the same as the Electra.

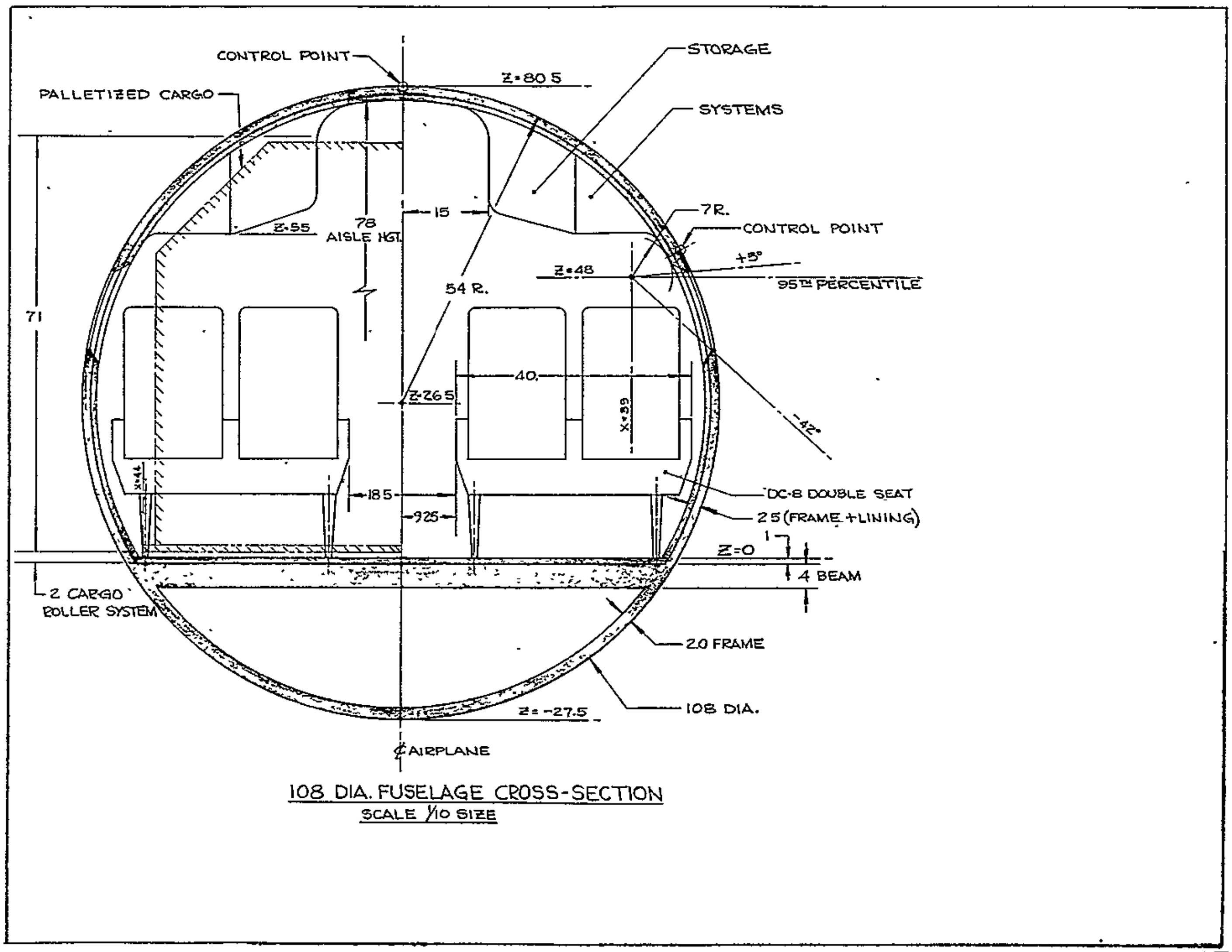
Landing gear mounting and retraction (on and into the nacelle) and propeller design has resulted in reasonably low ground clearance and near-minimum landing gear length. As shown, the turboprop ground clearance is 40 inches (102 cm). This can be decreased to 33 inches (84 cm) (as per FAR 25.925), which is only 13 inches (33 cm) higher than the turbofan aircraft with the aft-fuselage mounted engines.

The turboshaft engine size requirement can be satisfied by existing engines and the propeller is conventional.

2.2.3 Fuselage Cross Section and Interior Layouts

Figure 2-3 shows the circular cross-section preferred in the medium density design-to-cost studies. The depth below the floor is the minimum required to house the wing carry-through structure and/or the main landing gear.

The passenger cabin has DC-8 economy-class seating, a 30-seat capacity, 4 abreast at a 32-inch (81 cm) pitch, a single aisle, 18 inches (46 cm) wide and 78 inches (198 cm) high, and 95 percentile clearances. The cabin entrance, service and emergency exit doors are appropriate for FAA requirements. The cabin has one lavatory, bare minimum galley/buffet service or operation space, and upper baggage/cargo bays. Palletized cargo can also be accommodated.



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FUSELAGE CROSS SECTION

Figure 2-3

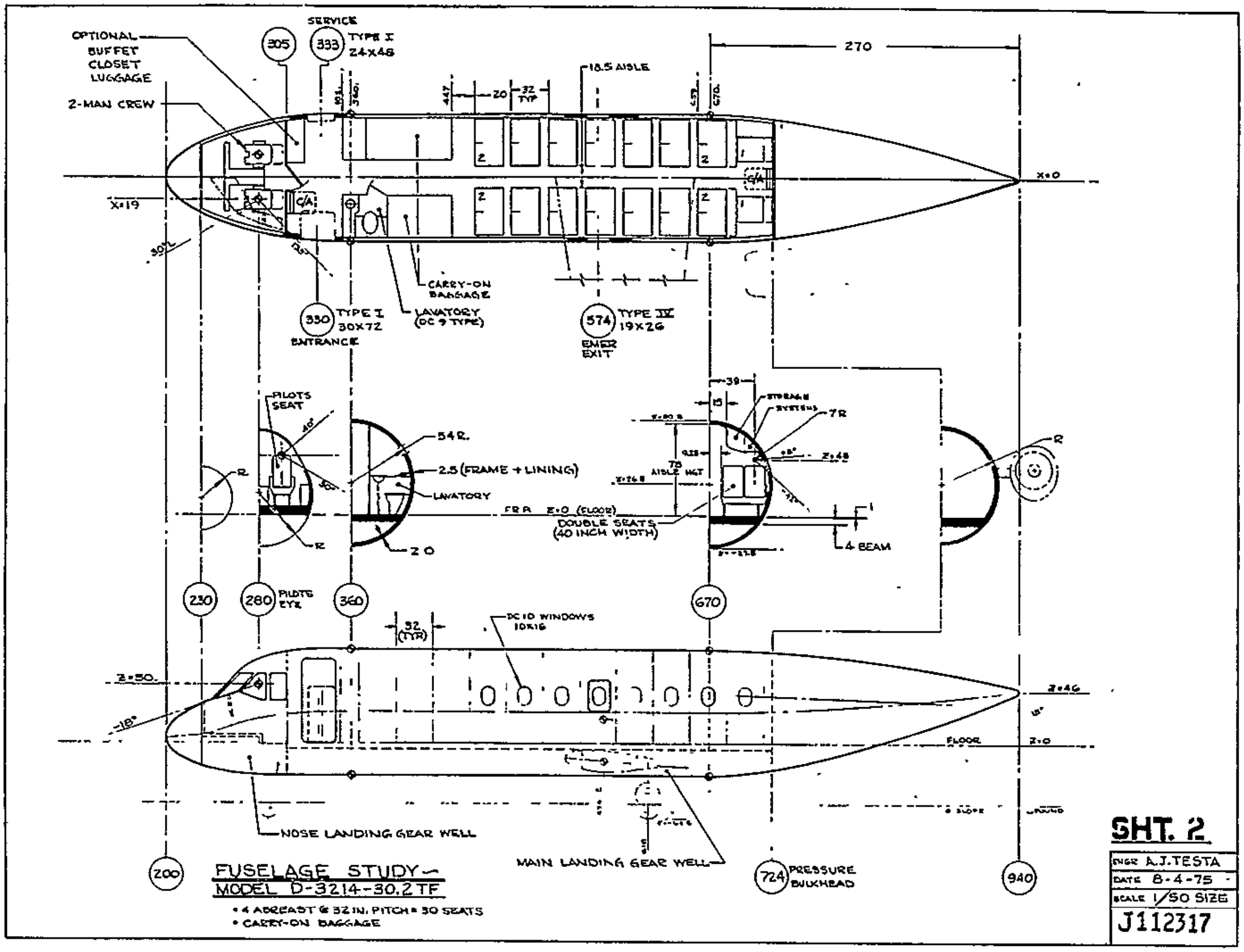
Figures 2-4 and 2-5 show the interior layouts. The turbofan fuselage is 30 inches (76 cm) longer than the turboprop. The increase in length is in the constant diameter section, because the nose and tail cone sections are the same lengths in either aircraft. The large area forward of the passenger seats accommodates the carry-on baggage compartment, stewardess' seat, buffet, closet, etc. The seating arrangement is 4-abreast and 32 inch (81 cm) pitch. Forward entrance and service doors and over-wing emergency doors are provided.

The turboprop fuselage also has forward entrance and service doors, but the emergency exits are at the rear. The 30 inch (76 cm) decrease in the length of the constant section, relative to the turbofan aircraft, is achieved by extending the cabin further into the tail cone because of the absence of the aft-fuselage-mounted engines. Commonality between the turboprop and turbofan fuselages, with either wing-mounted or aft-fuselage-mounted engines on the latter was not investigated.

2.3 Propulsion, Aerodynamics and Weight Data

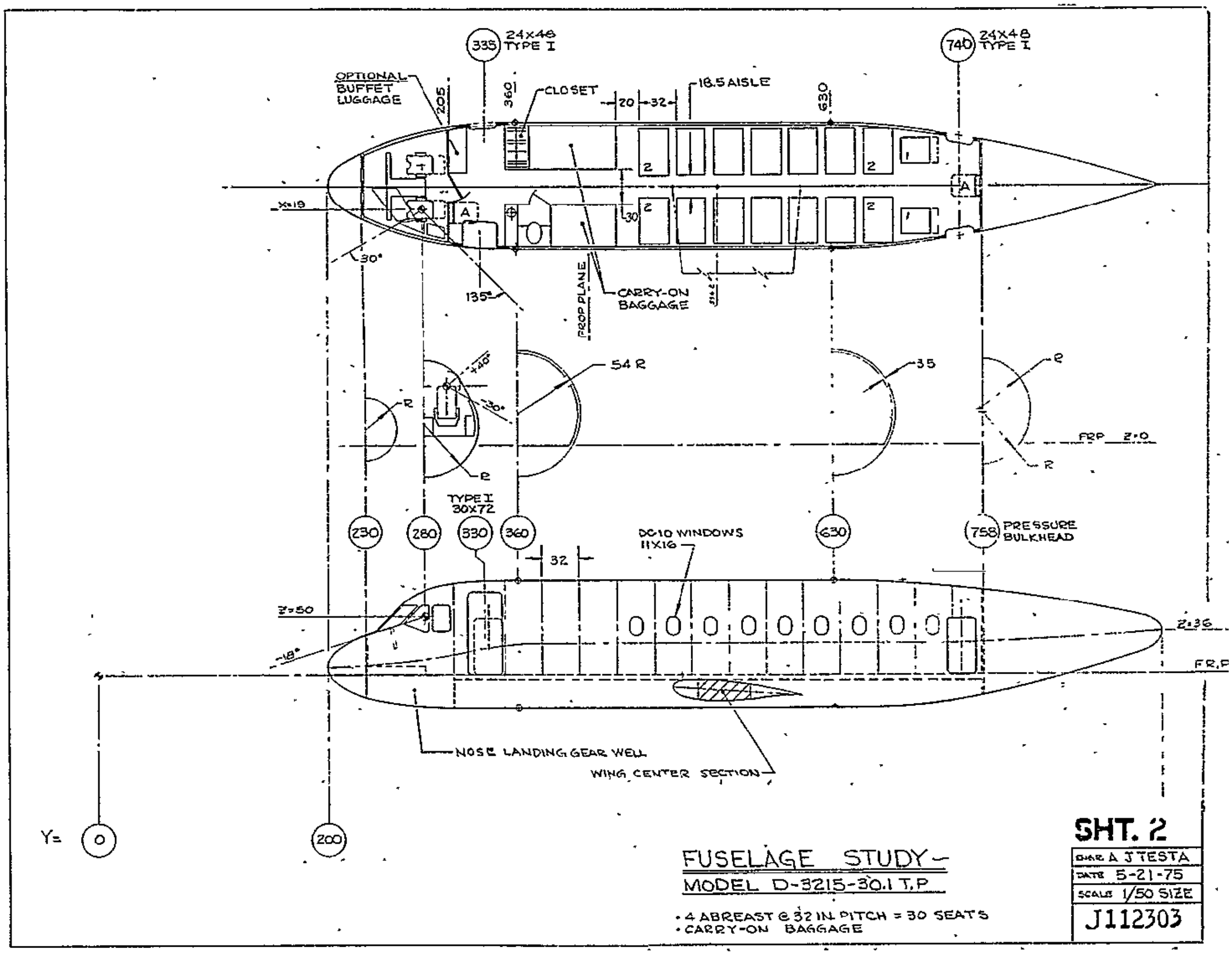
The fixed-pitch turbofan engine, with a BPR of 6 and an FPR of 1.45, was selected in the original study because an engine with these cycle characteristics has a low noise level, fuel consumption, development cost and technical risk.

The turboshaft engine and conventional propeller propulsion system was selected because of availability and a still lower cost, fuel consumption and technical risk. The engine and propeller combination was designed to provide the required takeoff thrust with maximum cruise speed, minimum diameter and a low noise level. In order to ensure attainment of exterior and interior acoustic requirements, the propeller characteristics were nearly



TURBOFAN: INTERIOR LAYOUT

Figure 2-4



TURBOPROP: INTERIOR LAYOUT

Figure 2-5

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identical to those of the Electra (i.e., 4BLX 163AFX0.286C_{L_i} x 720 fps).

Listed below are the basic characteristics defining two of the propellers studied:

Propeller: Hamilton-Standard Conventional (Red Handbook)

Four Blades: 0.3 Design Lift Coefficient

Activity Factor (per blade)	Diameter (inches) (cm)	C_{P_o}	C_{T_o}	SHP_o	kw
180	140 (356)	0.501	0.371	3,344	2,494
220	133 (338)	0.564	0.411	3,390	2,528

The design condition is 0.65 Mach at 22,000 feet (6,706 m) and 0.364 thrust-to-weight ratio for takeoff (the same as for the turbofan). These turboshaft engine and propeller installations are capable of providing 0.65 Mach from 22,000 to 25,000 feet (6,707 to 7,620 m), 0.64 Mach at 20,000 and 30,000 feet (6,096 and 9,144 m), and 0.62 Mach at 11,000 feet (3,353 m). Figure 2-6 illustrates the cruise performance characteristics of the selected propeller (220 activity factor). The power coefficient lines show that the propeller efficiency exceeds a minimum of 80 percent throughout the buffet-limited performance regime from 11,000 to 25,000 feet (3,353 to 7,620 m).

Tables 2-2 and 2-3 contain the physical characteristics of the selected aircraft. Although a tracked flap was selected in the original study, hinged flap was used for this study aircraft because of growth possibilities and wing-fuel-volume limitations of the tracked flap configuration. The tracked flap may be used to obtain shorter field lengths or to increase

HAMILTON STANDARD CONVENTIONAL PROPELLER

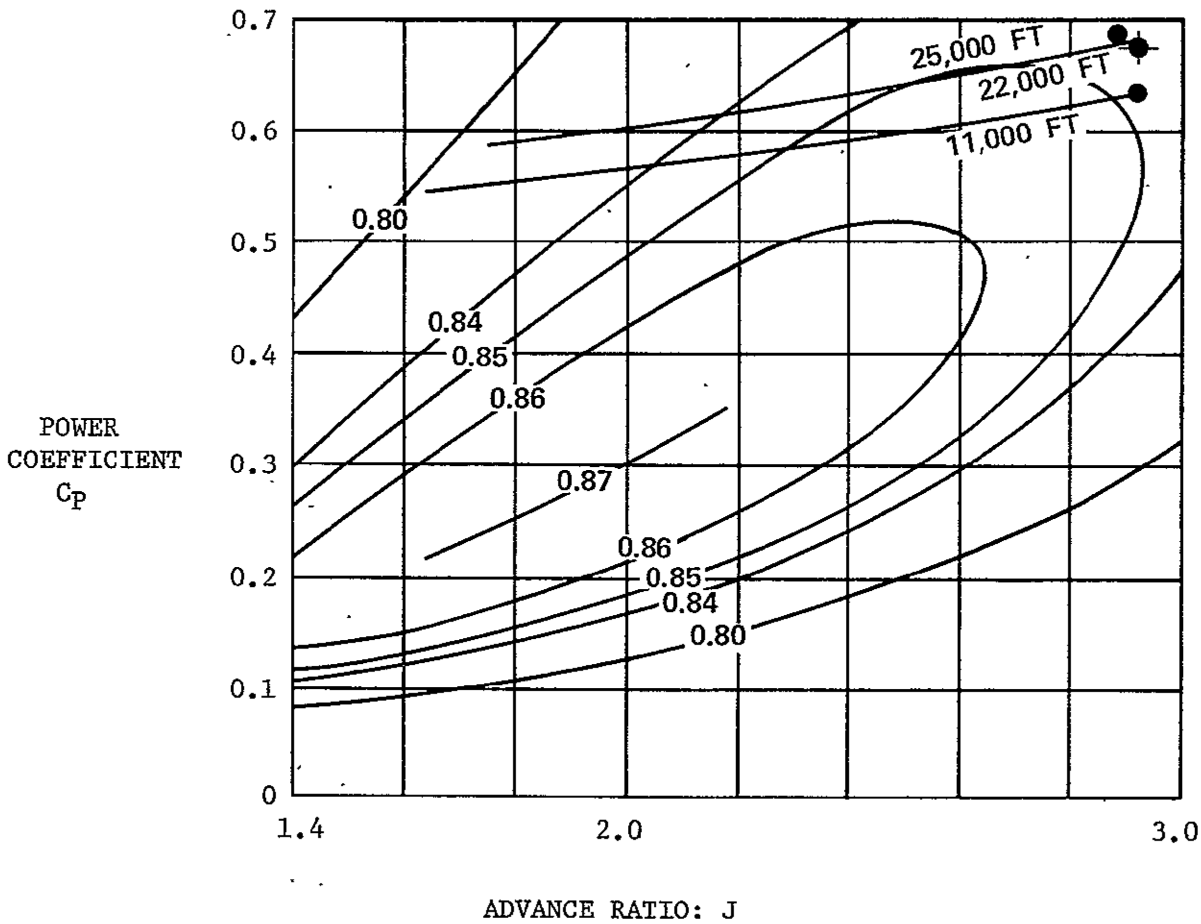
DESIGN CONDITION = 0.65 MACH AT 22,000 FT

NO. BLADES = 4

ACTIVITY FACTOR = 220

$C_{Li} = 0.3$

TIP SPEED (STATIC) = 720 FPS



HAMILTON STANDARD CONVENTIONAL PROPELLER

FIGURE 2-6

TABLE 2-2

PHYSICAL CHARACTERISTICS

30-PASSENGER AIRCRAFT

		TURBOPROP	TURBOFAN
FLAP TYPE		HINGED	HINGED
STAGE LENGTH	(N MI) (KM)	1 x 563 (1043)	1 x 563 (1043)
SEATS	(NO.)	30	30
FIELD LENGTH	(FT) (M)	4,500 (1372)	4,500 (1372)
WING AREA	(SQ FT) (M^2)	370.9 (34.4)	368.8 (34.3)
ASPECT RATIO		10.5	9.0
ENGINE POWER		2 x 3390 (ESHP) (2 x 2528 kw)	2 x 5920 lb. (2 x 26,337 N)
HORIZ/VERT TAIL AREA	(SQ FT) (M^2)	130.2/117.7 (12.1/10.9)	98.4/84.9 (9.1/7.9)
HORIZ/VERT TAIL ARM	(IN.) (CM)	283/283 (719/719)	348/273 (884/693)
HORIZ/VERT TAIL VOLUME COEFFICIENT		1.27/0.120	1.103/0.091
WING LOADING	(LB/SQ FT) (Kg/M^2)	88.0 (180.2)	88.3 (180.8)
THRUST-TO-WEIGHT RATIO		0.364	0.3634
FUEL FRACTION		0.1465	0.1711
FUSELAGE DIA/LENGTH	(IN.) (CM)	108/710 (274/1803)	108/740 (274/1880)

TABLE 2-3

PHYSICAL CHARACTERISTICS WEIGHT DATA

30-PASSENGER AIRCRAFT

ITEM: WEIGHT (LB/KG)	TURBOPROP		TURBOFAN	
	LB	KG	LB	KG
WING	3,229	1,464	3,097	1,404
HORIZONTAL TAIL	562	255	453	205
VERTICAL TAIL	440	200	677	307
FUSELAGE	5,015	2,274	4,290	1,946
LANDING GEAR	1,436	651	1,303	591
POWER PLANT INSTL.	4,102	1,860	4,441	2,014
FLT CONT, INSTL, HYD/PNEU, ELEC	2,022	917	1,941	880
AVIONICS	436	198	436	198
FURNISHINGS	2,726	1,236	2,623	1,190
AIR COND, ICE PROTECT	702	318	744	337
MANUFACTURER'S WEIGHT EMPTY	20,870	9,465	20,005	9,072
OPERATOR'S ITEMS	987	448	987	448
OPERATOR'S WEIGHT EMPTY	21,857	9,912	20,992	9,520
PAYLOAD	6,000	2,721	6,000	2,721
MISSION FUEL	4,782	2,169	5,572	2,527
MAXIMUM TAKEOFF WEIGHT	32,639	14,802	32,564	14,768

design versatility for stretched versions in the family concept. As aircraft decrease in size, fuel containment in the wing becomes more critical because wing volume varies with wing area to the three-halves power.

Wing loading and thrust-to-weight ratio are idential for both aircraft. However, the turboprop has a lower fuel fraction because of better fuel economy and a higher aspect ratio because of one-engine-out control requirements.

Compared with the turbofan aircraft, the manufacturer's or operator's weight empty of the turboprop aircraft is greater by nearly 900 pounds (408 kg) due principally to the acoustic insulation required in the fuselage. However, the turboprop aircraft has a lighter mission fuel load, i.e., lower by 14 percent or nearly 800 pounds (369 kg). Thus, the maximum takeoff gross weights are virtually identical.

2.4 Comparative Analysis

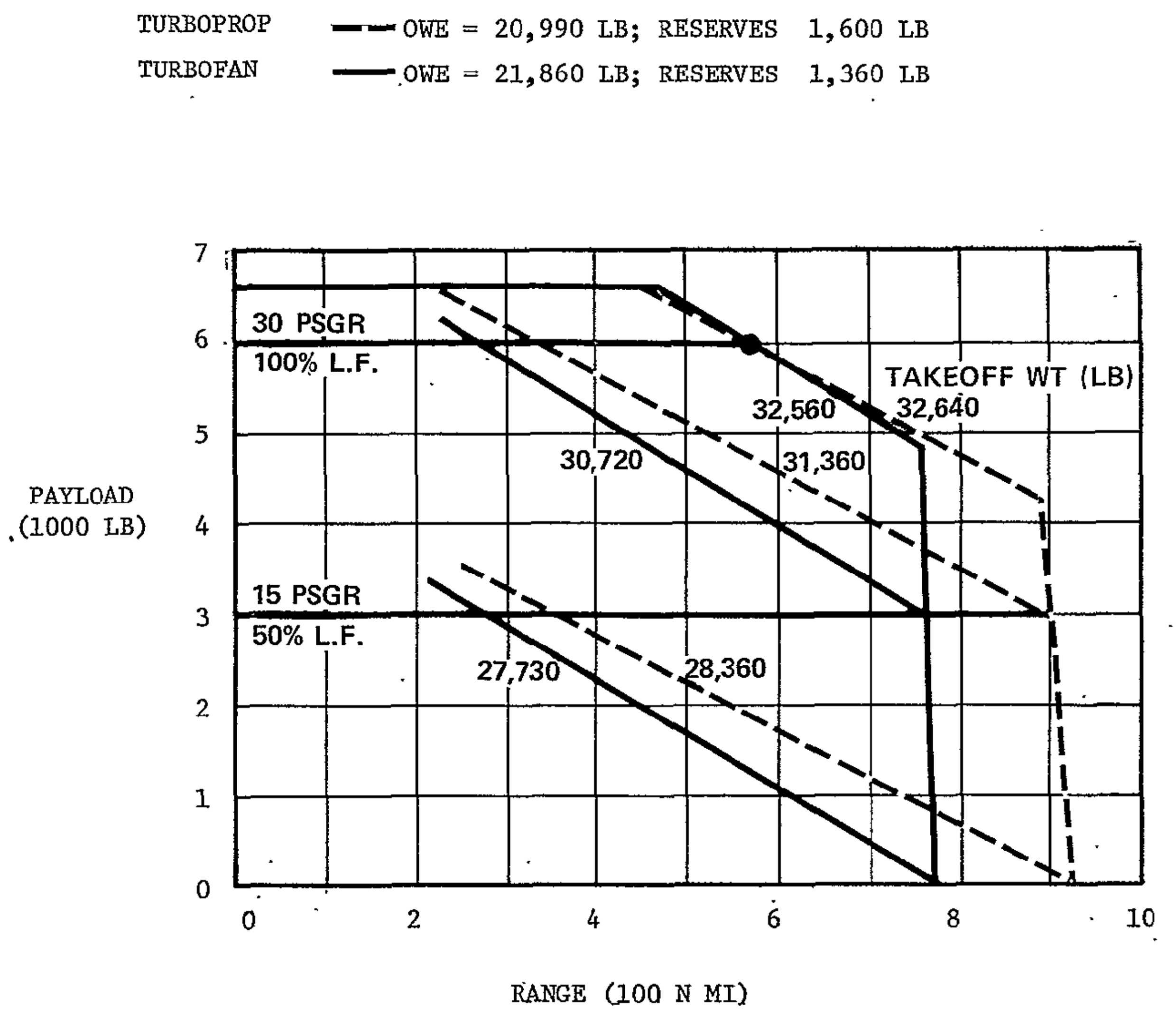
2.4.1 Payload, Block Fuel and Time vs. Range

Figure 2-7 depicts the payload-range capability of the turbofan and turboprop aircraft at high altitude cruise conditions. Both aircraft are designed for a single-stage range of 563 nautical miles (1,043 km) with a 30 passenger payload. At and below a load factor of 80 percent, the turbofan range capability is restricted by the maximum, wing-limited fuel capacity. The wing-limited fuel capacity of the turboprop occurs at a lower load factor (71 percent) and its fuel-limited range capability is nearly 20 percent higher.

At the normal operating load factor of approximately 50 percent, the takeoff weight will vary from about 31,500 to 27,500 pounds (14,286 to 12,472 kg) depending on the range.

PAYLOAD VS RANGE

30-PASSENGER AIRCRAFT, 0.65 MACH, 22,000 FEET



PAYLOAD VS RANGE

FIGURE 2-7

Figure 2-8, showing the block fuel of both aircraft at high and low altitudes, illustrates the better fuel economy of the turboprop aircraft. The lower altitude 11,000 feet (3,353 m) is the minimum flown on very short stage lengths, in order to avoid the 250 knot speed (463 km/hr) restriction below 10,000 feet (3,048 m).

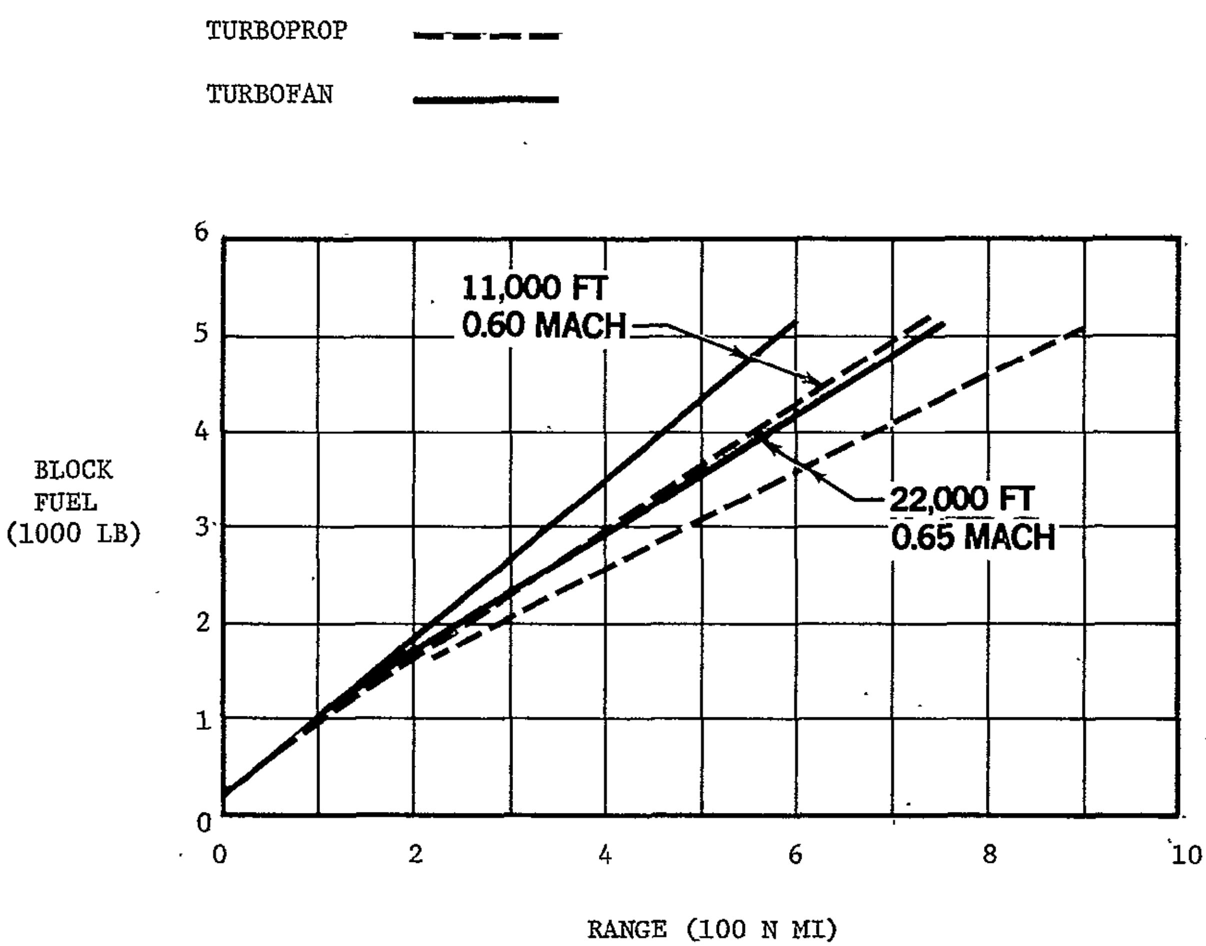
Figure 2-9 shows that both aircraft are designed for the same high altitude cruise condition 0.65 Mach at 22,000 feet (6,706 m). At 11,000 feet (3,353 m) they are cruised at 0.60 Mach, a value slightly below their maximum capabilities. Thus, the high and low altitude block times are nearly the same.

2.4.2 Multi-Stage Range Capability

Tables 2-4 and 2-5 show the unrefueled multi-stage range capabilities of the turbofan and turboprop aircraft at high and low altitudes and 100 percent and 50 percent load factors. Any combination of unequal stage lengths can be performed as long as the total fuel does not exceed the single-stage fuel at any given cruise and payload condition. At 22,000 feet (6,706 m), the turbofan can only perform a two-stage mission at 100 percent and 50 percent load factors. The minimum stage lengths (i.e., zero cruise, climb and descent only) are 233 and 225 nautical miles (432 and 417 km), respectively. At 11,000 feet (3,353 m), the turbofan can perform a six-and an eight-stage mission at 100 percent and 50 percent load factors. The minimum stage lengths are 56 and 53 nautical miles (104 and 98 km), respectively.

At 22,000 feet (6,706 m), the turboprop can perform a two- and a three-stage mission at 100 percent and 50 percent load factors. The minimum stage lengths are 150 and 140 nautical miles (278 and 259 km), respectively. At 11,000 feet (3,353 m), the turboprop can perform a five- and a nine-stage

BLOCK FUEL VS RANGE: 30-PSGR AIRCRAFT

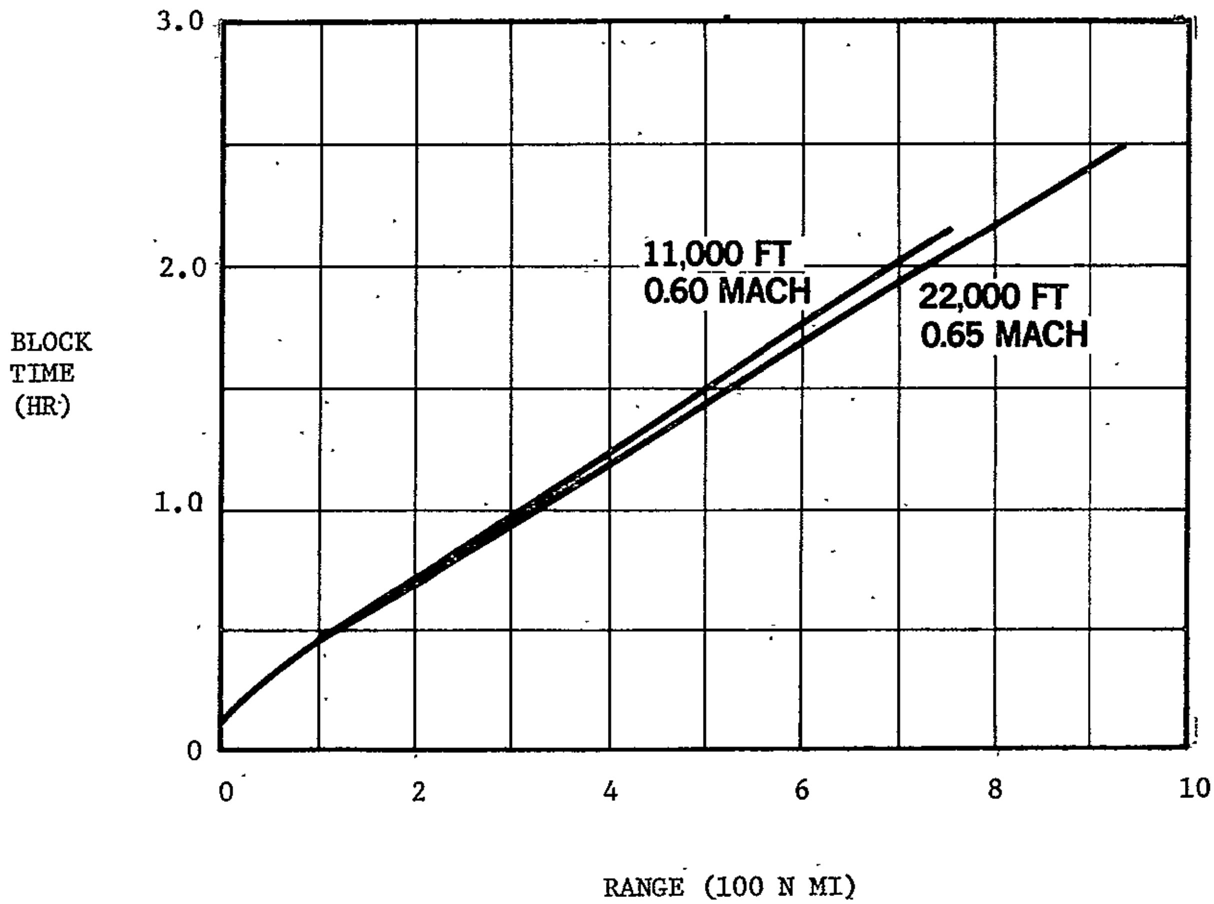


BLOCK FUEL VS RANGE

FIGURE 2-8

BLOCK TIME VS RANGE: 30-PSGR AIRCRAFT

TURBOFAN AND TURBOPROP



BLOCK TIME VS RANGE

FIGURE 2-9

TABLE 2-4

MULTI-STAGE RANGE CAPABILITY:

30-PASSENGER TURBOFAN AIRCRAFT

Cruise Altitude (Ft) & Mach No.	Payload (Lb)	Stages (No)	Stage Length (N Mi)	Block Fuel (Lb)	Block Time (Hr)
22,000 @ 0.65	6,000	1	564	3,911	1.63
		2	244	1,956	0.82
		*3	137	1,304	0.55
	3,000	1	753	5,024	2.09
		2	342	2,512	1.05
		*3	205	1,675	0.71
	6,000	1	458	3,911	1.38
		2	217	1,956	0.75
		3	136	1,304	0.54
		4	96	978	0.43
		5	72	782	0.37
		**6	56	652	0.33
11,000 @ 0.60	3,000	1	600	5,024	1.75
		2	288	2,512	0.93
		3	183	1,675	0.66
		4	131	1,256	0.52
		5	100	1,005	0.44
		6	79	837	0.38
		7	64	718	0.34
		**8	53	628	0.32

* These stages cannot be conducted as the minimum stage lengths (i.e., climb, zero cruise, and descent only) are 233 and 225 nautical miles, respectively.

** These stages can be conducted; the minimum stage lengths are 56 and 53 nautical miles, respectively.

TABLE 2-5

MULTI-STAGE RANGE CAPABILITY:
30-PASSENGER TURBOPROP AIRCRAFT

Cruise Altitude (Ft) & Mach No.	Payload (Lb)	Stages (No)	Stage Length (N Mi)	Block Fuel (Lb)	Block Time (Hr)
22,000 @ 0.65	6,000	1	562	3,422	1.56
		2	230	1,711	0.71
		*3	120	1,141	0.43
	3,000	1	911	5,139	2.45
		2	406	2,570	1.15
		3	237	1,713	0.72
		**4	153	1,285	0.51
	6,000	1	473	3,422	1.36
		2	215	1,711	0.68
		3	129	1,141	0.46
		4	85	856	0.34
		5	60	684	0.28
		*6	42	570	0.23
11,000 @ 0.60	3,000	1	742	5,139	2.06
		2	350	2,570	1.03
		3	219	1,713	0.69
		4	154	1,285	0.51
		5	115	1,028	0.41
		6	89	857	0.34
		7	70	734	0.29
		8	56	642	0.26
		9	45	571	0.23
		*10	36	514	0.21

* These stages cannot be conducted as the minimum stage lengths (i.e., climb, zero cruise, and descent only) are 150, 46 and 39 nautical miles, respectively.

** This stage can be conducted; the minimum stage length is 140 nautical miles.

mission at 100 percent and 50 percent load factors. The minimum stage lengths are 46 and 43 nautical miles (85 and 80 km), respectively.

2.4.3 Airport Runway Length Survey

The aircraft was designed for a balanced takeoff and landing field length of 4,500 feet (1,372 m). In the original study this runway length was deemed satisfactory for all of the local service carriers included in the original market. With the addition of trunk carriers to the study, more airports were added to the domestic traffic model. It was assumed trunk-only airports would be adequate without further evaluation.

A total of 32 commuter airlines were added to the data base. All of the airports served by these commuters were surveyed for runway length. The results of this survey are shown in Table 2-6. The local carrier airports, divided into classes of 500 feet (152 m) from 2,500 feet (760 m) and longer are shown in the left portion of the diagram. Commuter airports are classified and presented in the right portion. Note that 98.9 percent of local service airports have runways of 4,500 feet (1,372 m) or greater. Similarly, commuter airports provide runways in excess of 4,500 feet at 89.7 percent of the sites served.

2.5 IFR Versus VFR Sensitivity Studies

A representative survey of the projected instrument flight rules (IFR) versus visual flight rules (VFR) and air traffic control (ATC) environment was conducted and an evaluation was made of the present and future ATC activities at the Denver Stapleton International Airport - a typical busy hub airport. Eastbound and westbound routes to Denver were chosen for some detailed examinations. Terminal environments of the 1980's were studied to

TABLE 2-6

SURVEY OF RUNWAY LENGTHS ON AIRPORTS

USED BY LOCAL SERVICE AND COMMUTER AIRLINES

RUNWAY LENGTH (FT)	LOCAL SERVICE		PERCENT DISTRIBUTION		COMMUTER	
	EACH CLASS	CUMULATIVE			EACH CLASS	CUMULATIVE
2500 - 2999	1	1			1	1
3000 - 3499	0	1			3	4
3500 - 3999	2	3	0.7	6.2	5	9
4000 - 4499	2	5	1.1	10.3	6	15
4500 - 4999	13	18	4.1	13.8	5	20
5000 - +	425	443	95.9	86.2	125	145

ascertain potential time savings in terminal flight operations. An estimate of time and fuel savings was made for VFR and IFR comparative operations.

Typical instrument flight rule approaches to Denver Stapleton are shown in Figure 2-10. Minimum operating altitudes are specified because of terrain clearance requirements.

A standard westbound IFR route from Kansas City, Missouri, to Denver is diagramed in Figure 2-11. The departure and approach routes are straight and show no potential for reduction in air maneuver time. Both IFR and VFR paths in the terminal area follow the same routes. For the eastbound IFR approach to Kansas City, IFR and VFR are somewhat different, as shown in the small sketch. The time differential, however, appears insignificant.

The IFR flight path from Grand Junction eastbound to Denver is shown in Figure 2-12. The takeoff pattern from Grand Junction requires a directed climb to altitude because of terrain clearance requirements. The approach to Denver involves a rather circuitous path in both the VFR approach and the IFR approach. The IFR approach involves flying a leg longer by about 50 nautical miles (93 km) as compared with the VFR pattern.

The planned approach patterns for area navigation in the Denver terminal control area for 1982 implementation are shown in Figure 2-13. The fanlike approach pattern illustrates the flexibility of the proposed microwave landing system curved-path IFR approach.

For Grand Junction-Denver area navigation approaches in the 1980's, Figure 2-14 illustrates a potential approach path which could shorten a standard IFR approach by about 10 miles (18 km) compared with current practice.

TERMINAL CONTROL AREA
DENVER
IFR ARRIVAL ROUTES

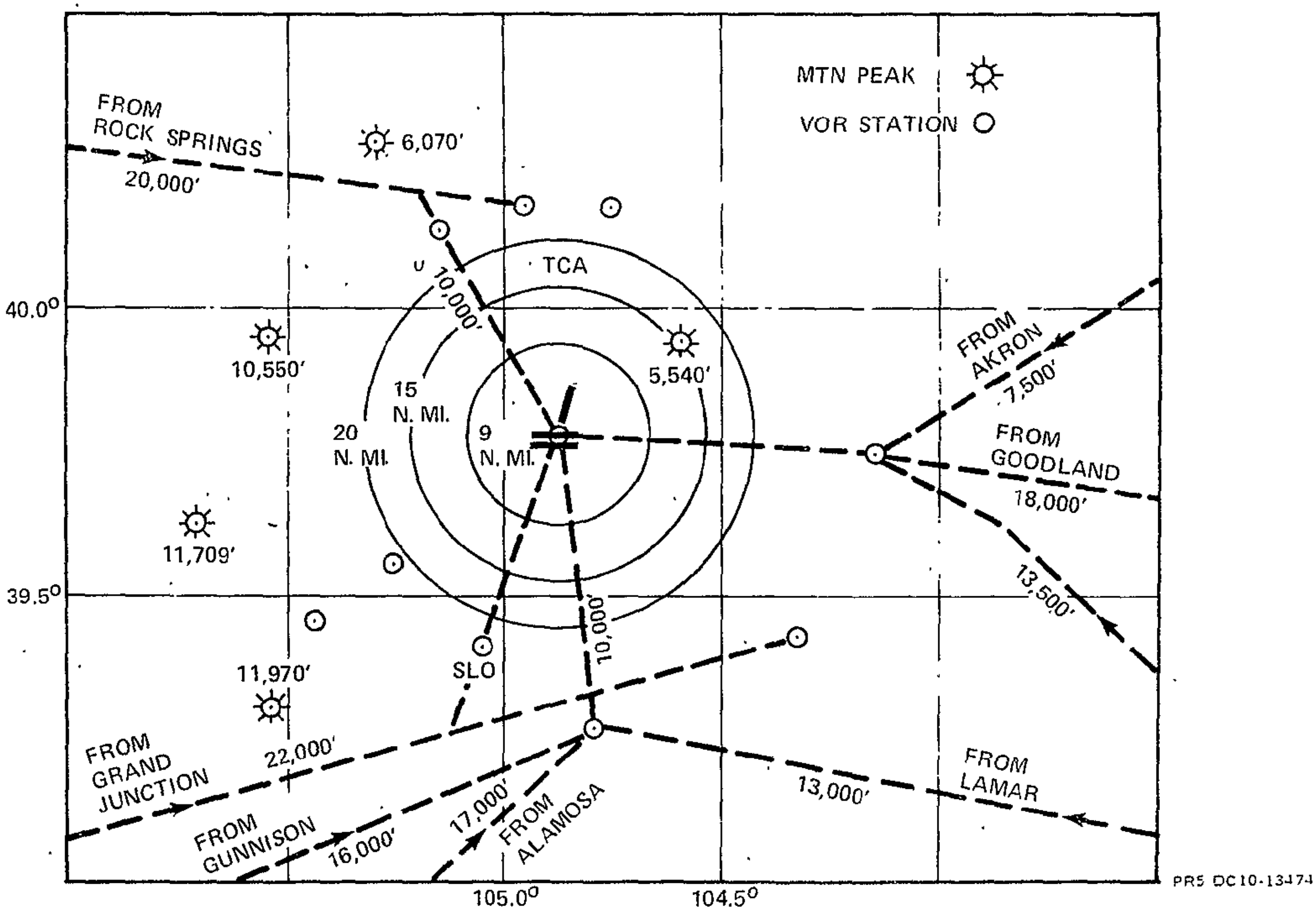


Figure 2-10

IFR FLIGHT — KANSAS CITY TO DENVER
(WEST FLOW)

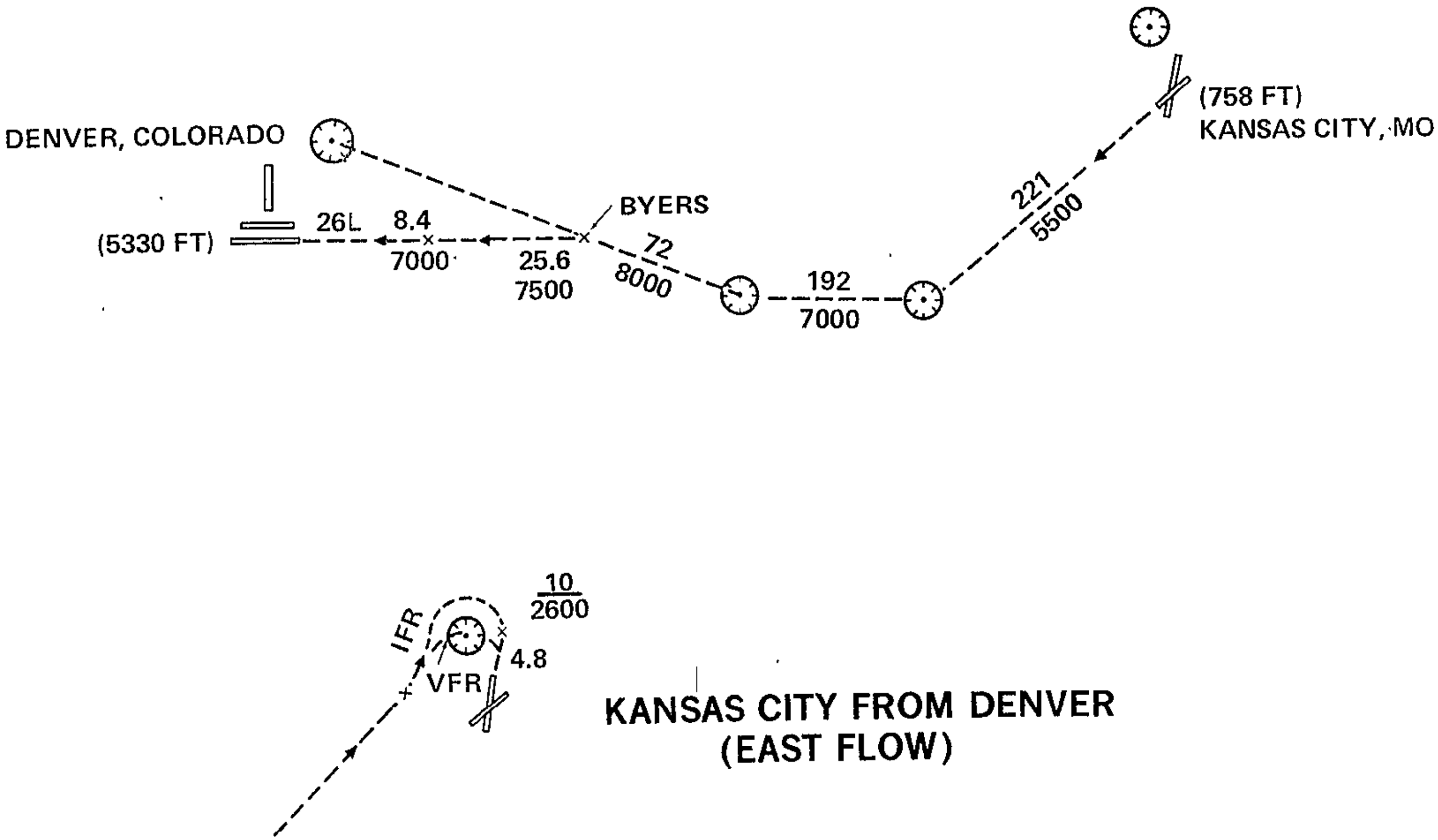
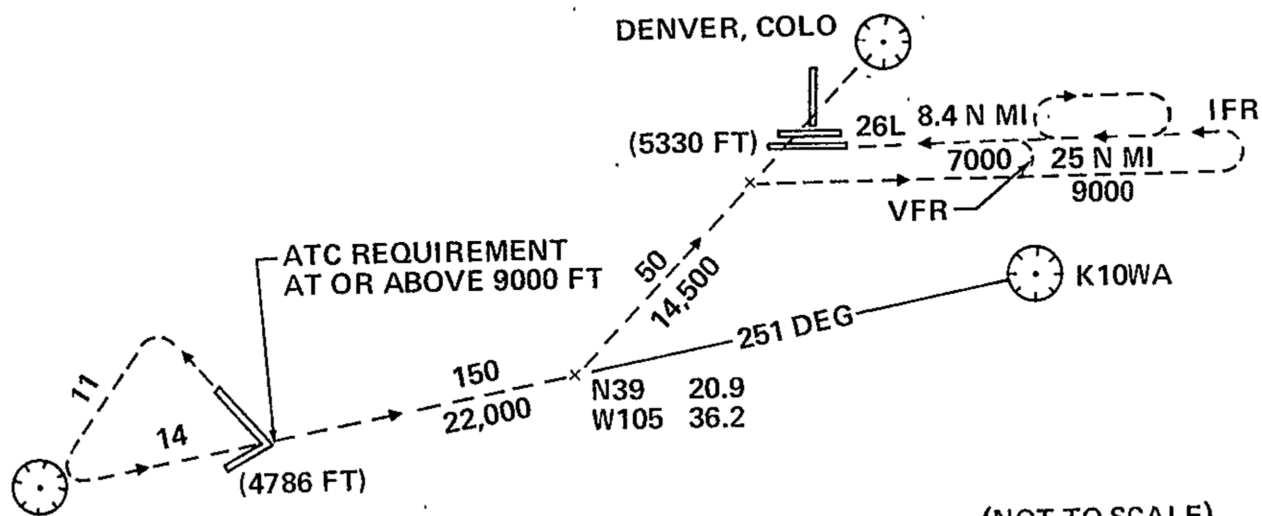


Figure 2-11

PR5-DC10-13360

IFR FLIGHT — GRAND JUNCTION TO DENVER
(EAST FLOW)



(NOT TO SCALE)

TIMBERLINE THREE (GJT-TIMB3)
STANDARD TERMINAL ARRIVAL ROUTE

PR5-DC10 13359

Figure 2-12

AREA NAVIGATION ROUTES DENVER
1982
CURVED PATH OPERATION WEST FLOW

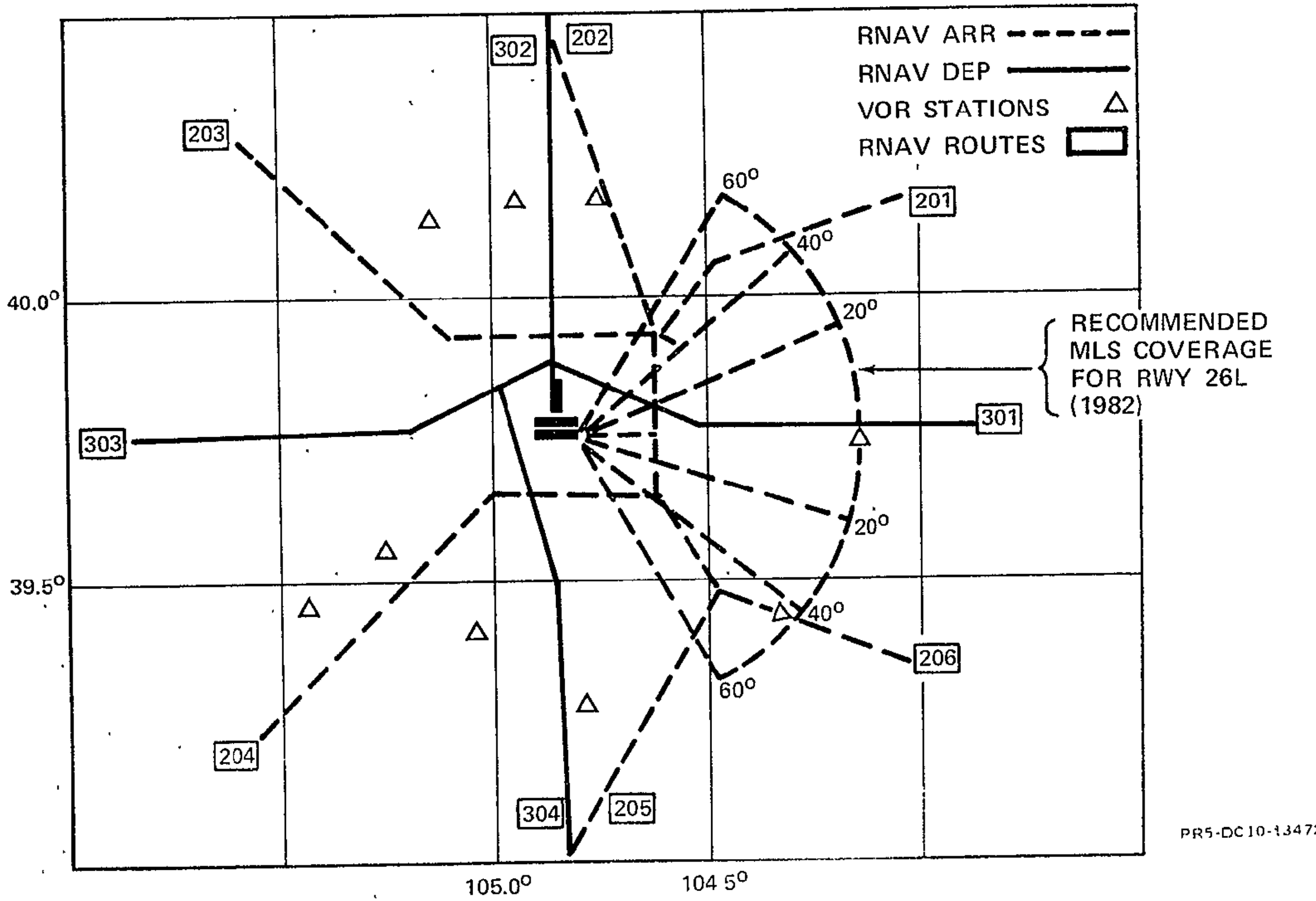


Figure 2-13

GRAND JUNCTION TO DENVER
ALTERNATE TERMINAL ROUTE

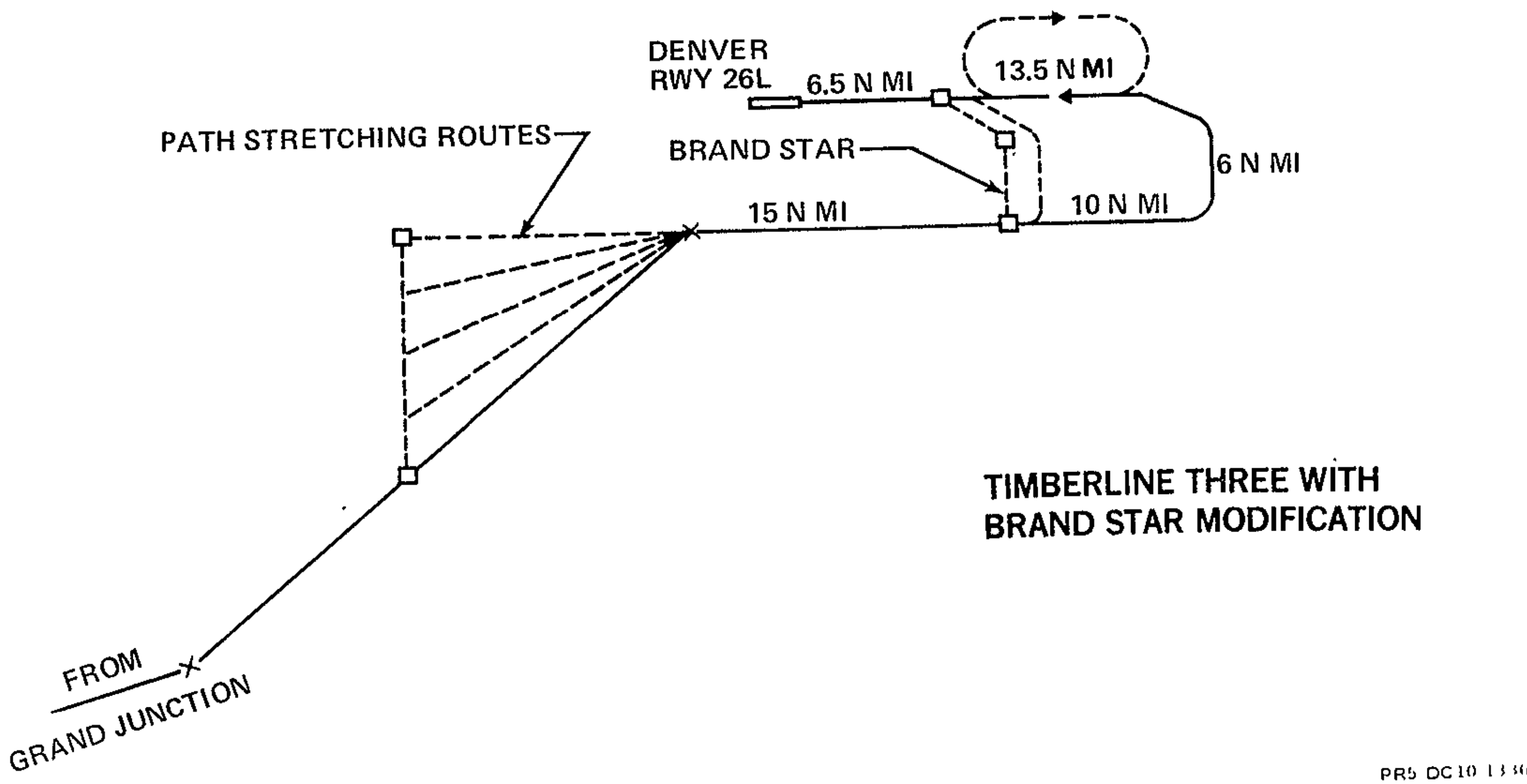


Figure 2-14

"Timberline Three" is an approach route designation. "Brand Star" is also an FAA designation for this particular approach path. STAR is an acronym for a standard terminal arrival route.

Separation of IFR traffic on approach may be accomplished as shown in Figure 2-15. The runway instrumentation is a microwave landing system with distance measuring equipment (DME). The fan path approach can be used to save time and distance on a pattern approach. In addition, commercial jet traffic could be separated by weight class as indicated. The 30TF study aircraft is in the light jet category and could follow the shortest approach path. Compared with a standard (current 1975) approach on IFR, this shortened approach path saves a maximum of 23 nautical miles (42.6 km) and 8.2 minutes of flight time. It also reduces fuel consumption by 235 pounds (106.6 kg).

A brief summary of ATC evaluations is presented as Table 2-7. A comparison of VFR was made with the three IFR approaches discussed. The standard IFR approach analyzed at Denver showed a path distance of 28.6 miles (53 km) greater than the VFR. Both the IFR Brand Star and delay fan approach method approximated the VFR method with a savings of 23.5 nautical miles (43.5 km) over the standard IFR method. This projects a savings of 9.6 minutes or $24.94 in DOC. This included a fuel savings of $9.12 using the study price of 26 cents per gallon.

To illustrate some of the operational factors considered in evaluating ATC problems, a series of comments are presented in Table 2-8. These comments are pertinent to Stapleton Airport. They probably are applicable to other airports of similar size and function.

REDUCED FLIGHT PATHS ON FINAL APPROACH
WITH IFR SEPARATION

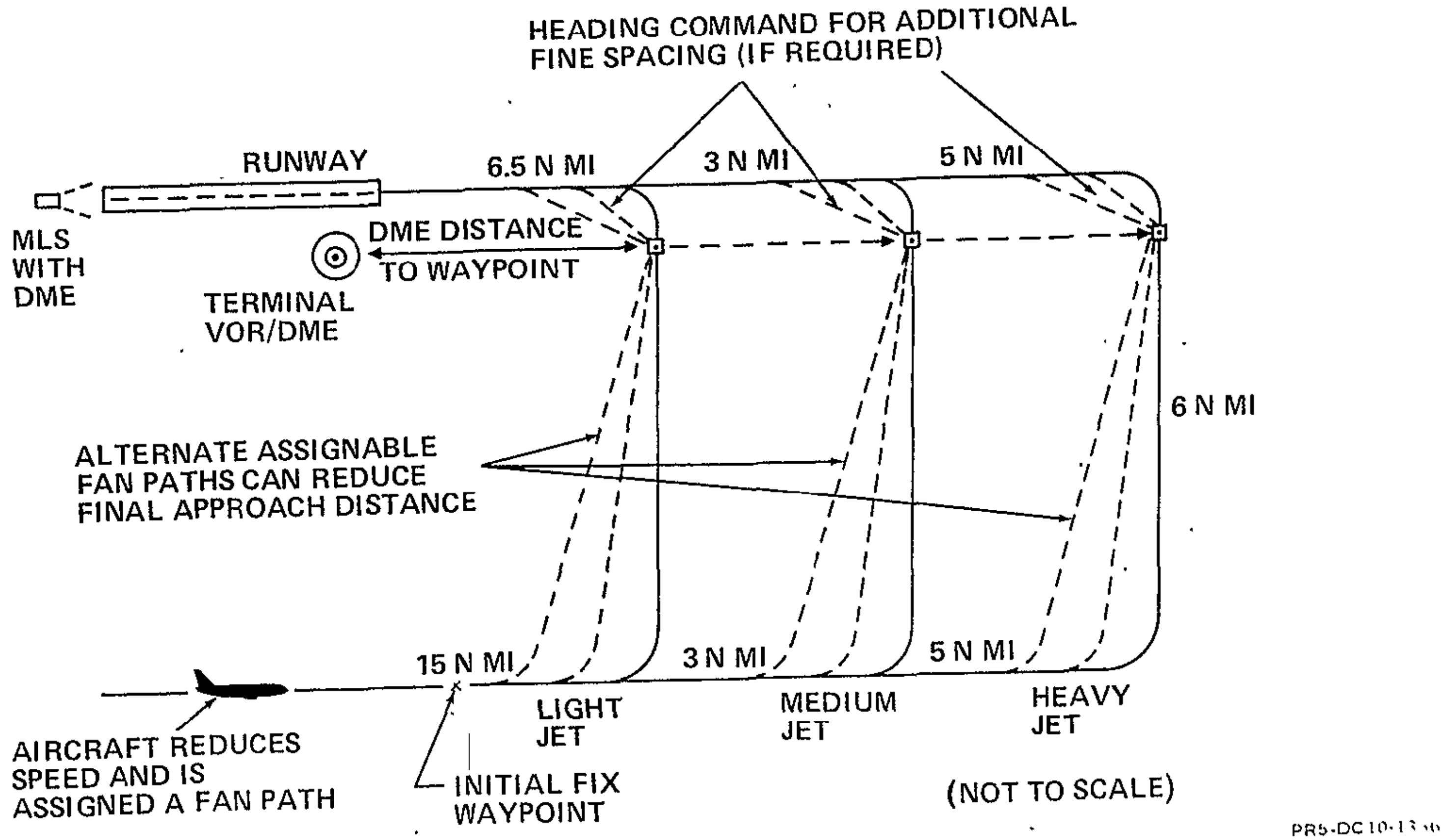


Figure 2-15

TABLE 2-7

AIR TRAFFIC CONTROL

IFR VS VFR OPERATIONS

APPROACH METHOD	APPROACH PATH DISTANCE (N. MI.)	APPROACH PATH REDUCTION (N. MI.)	APPROACH TIME (MIN.)	APPROACH FUEL (LBS)	FUEL SAVINGS (LBS)
IFR STANDARD	51.0	BASE	17.8	510	BASE
VFR	22.4	28.6	7.8	224	286
IFR BRAND STAR	27.5	23.5	9.6	275	235
IFR DELAY FAN	27.5	23.5	9.6	275	235

DOC SAVINGS FOR 23.5 N. MI. = $24.94

FUEL SAVING INCLUDED = $9.12

TABLE 2-8

SUMMARY ATC OPERATIONAL FACTORS

DENVER STAPLETON AIRPORT	1975	1985	COMMENTS
Total scheduled aircraft movements (departures and arrivals)	544/day (estimates)	820/day (estimates)	Airport may be capacity limited by 1985 Assumes 4%-5% growth rate average per annum
Frontier Airlines movements at Denver	64/day (estimates)	96/day (estimates)	4%-5% per annum growth rate
Runways, taxiways and exists	--	High speed exits or multiple turnoffs required	Need to reduce maneuver time between runway and arrival/departure gates
Enroute and terminal navigation aids (VOR/DME)	Spotty and intermittent cover due to mountainous terrain	Use of R-Nav or LORAN can provide required navaid coverage	Improved enroute and terminal navigation routes will have to be constructed
Landing system	Standard ILS	Microwave on Rwy 26 at Denver	Can provide multipath approaches to the runway with curved path operation Runway co-located DME
Area navigation	none	4D	Improved positioning accuracy and separation on approach

3.0 SIMULATION ANALYSES

A baseline operational simulation with the study aircraft was conducted in a traffic demand model representing the total U.S. domestic market for air service to small communities. Both a baseline operational evaluation and a set of parametric sensitivity analyses were conducted with this demand model.

A second simulation with similar objectives was performed in a model drawn from routes flown by Frontier Airlines. The selected routes were those on which Twin Otter and Convair 580 aircraft were operated in 1974. The traffic growth was projected to 1985 for the routes retained with the definition of the small community market - e.g., 400 statute miles (644 km) travel distance and 300 travelers per day per route.

A third simulation was conducted on the selected Frontier Airlines network. This study developed a fleet itinerary and schedule for the 1985 traffic forecast with the 30-passenger study aircraft.

3.1 Characteristics of Study Aircraft

The study aircraft included a turbofan and turboprop-powered configuration with capacity for 30 passengers or a payload of 6,000 pounds at the full design range. Detailed characteristics of the aircraft have been presented in Section 2.0, Aircraft Analysis. For the airline operational simulation, general aircraft characteristics are presented in Table 3-1. Note that speed, payload and range are the same for each. The block time function is adjusted to average performance at the short stage lengths in the traffic model. The DOC function for the turboprop reflects a lower fuel

TABLE 3-1

STUDY AIRCRAFT CHARACTERISTICS FOR
OPERATIONAL SIMULATION

Item	Turbofan	Turboprop
Passenger Seats	30	30
Flight Crew	2	2
Cabin Attendant	1	1
Design Range: n.mi.	563	563
st.mi.	648	648
km	1,043	1,043
Payloads: pounds	6,000	6,000
kg	2,720	2,720
Cruise Speed: Mach No. at 22,000 ft. (6,707 m)	0.65	0.65
Block Time Function: trip hours at range (n.mi)	0.20 + .00245 x R	
Trip Cost Function: dollars per trip at range (n.mi)	56.27 + 1.222 x R	62.99 + 0.772 x R
Unit Price at 400 Units ($ million)	2.300	1.977
Development Program Cost ($ million)	85.0	76.0

consumption and a lower price for the aircraft compared with the turbofan. The cost function for the 30-passenger turbofan (30TF) is revised from that shown in the base Medium Density Study as shown in Appendix A-4. This reflects the shorter design range for the current 30TF evaluated herein. The 30-passenger turboprop (30TP) is a new design completely. The base study did not include this aircraft in the medium density evaluations.

3.2 Simulation Guidelines

A general set of guidelines was applied in the airline operational simulations. In the baseline evaluation, the 30-passenger turbofan-powered study aircraft was analyzed in a noncompetitive situation. Simulation guidelines included:

- A basic revenue yield function was based on CAB Class 7 Phase 9 fares for 1974.
- All costs were expressed in constant 1974 dollars.
- Fuel costs were 26 cents per gallon.
- The DOC basic computational format was drawn from the NASA Medium Density Study. The direct operating trip costs for the study aircraft were computed with characteristics of the study aircraft. Trip costs were then expressed as a constant dollar amount plus a dollar per mile factor times the trip distance (see Appendix A-4).
- An IOC formula of 53 percent of revenue was based on a typical fleet evaluation with the Short-Haul Economic Study results (NAS2-8549).
- A minimum flight schedule for any 1985 fleet solution was required to provide at least the same flight frequencies as scheduled in 1974.

- A target system load factor of 60 percent was applied to basic fleet planning.
- Net Operating Income was defined as passenger revenue less DOC and IOC for the fleet.

Various sensitivity studies were conducted with the 30-passenger turbofan-powered aircraft as follows:

- A competitive fleet evaluation with both a 30 and a 40-passenger study turbofan-powered aircraft.
- Higher growth rates applied to commuter traffic as compared with the initial baseline model.
- The effect of fare increases on net operating income.
- The impact on DOC and net operating income of savings in aircraft maneuver time.

The same set of simulation guidelines was applied to the traffic model based on the selected Frontier Airlines network. A competitive evaluation was made with the 30-passenger turbofan and the DHC-7, the Falcon 30, and the SD3-30. Parametric variations were evaluated to determine the operational and economic impact of changes in system load factors and annual utilization.

An airline scheduling analysis was conducted with the 30-passenger aircraft using the Douglas Airline Schedule Planning and Evaluation Model. The effect on fleet performance was measured for changes in service levels.

4.0 ANALYSIS OF AIR SERVICE TO SMALL COMMUNITIES

The base data for the small communities domestic traffic market is shown in Table 4-1. The data is organized into four service classes or market categories. Note that for the commuter carriers, trips to and from large hubs were slightly greater in number than to other hubs. By contrast, the regional and trunk carriers (major carriers) served appreciably more medium and small size communities in this model. This reflects application of the 300 passenger per day limit applied to each route in the model (see Appendix A-1 for greater detail). The seat capacity data illustrates the limitation of commuter carriers to the more important carriers flying aircraft of 15 seats or more. Among the regional and trunk carriers, a wide range of vehicle capacities is noted. The applied load factor data was used to translate flight schedules and seat capacity into RPM with the base data shown for 1974 and the projections to 1985.

The baseline evaluation of noncompetitive fleet performance with the 30-passenger turbofan-powered study aircraft is summarized in Table 4-2. For convenience, results are shown for commuters and major carriers. On commuter routes, the 30-passenger aircraft generated 302,000 trips. This was slightly greater than the 1974 schedule of 297,000. However, the average system load factor was only 37.2 percent, reflecting the low growth rate applied to this class of traffic from 1974 and requirements for minimum trips on many routes. A fleet size of 46 was the total potential requirement for these commuter carriers in the 1985 baseline solution. A sensitivity analysis revealed the effect of higher commuter traffic growth rates was an increase in fleet size, in the number of annual aircraft trips, and in the average system load factor. A growth rate of 12 percent resulted in an average

TABLE 4-1

DOMESTIC TRAFFIC MODEL

1974 Base and Projections to 1985

MARKET CATEGORY	SCHEDULED AIRCRAFT TRIPS (000, 1974)	AVERAGE SEAT CAPACITY		APPLIED LOAD FACTOR	REVENUE PASSENGER MILES (Millions)	
		1974	1985		1974	1985
COMMUTERS:						
Large Hubs	158	18	22	.65	210	261
Other Hubs	139	18	22	.30	59	73
MAJOR CARRIERS:						
Large Hubs	342	66	113	.65	2,530	4,327
Other Hubs	452	61	105	.50	1,502	2,569
TOTALS	1,091				4,301	7,230

NOTE: 1,454 Airport Pair Segments

- 1974 base derived from Official Airlines Guide, August 1974
- Traffic growth rates 1974-1985: 2% for commuters, 5% for major carriers

TABLE 4-2

OPERATIONAL SIMULATIONS - FLEET PERFORMANCE

1985

Noncompetitive

30-Passenger Aircraft

MARKET CATEGORY	FLEET SIZE	AIRCRAFT TRIPS (Millions)	AVERAGE STAGE (St.Mi.)	AVERAGE BLOCK SPEED (MPH)	AIRCRAFT UTILIZATION (Hr/Yr)	SYSTEM LOAD FACTOR (%)
COMMUTERS	46	.302	105	243	2,679	37.2
MAJOR CARRIERS	466	2.402	161	295	2,799	59.8
TOTAL MARKET	512	2.704	157	290	2,788	58.2

NOTE: Target System Load Factor = 60%

- Traffic Growth Rates: 2% for commuters, 5% for major carriers

system load factor of about 60 percent. Details of this analysis are presented in Section 4.1.2.

On the major carrier low density routes, a growth in RPM to 1985 indicated a much larger potential. A 30-seat aircraft fleet was simulated to generate 2,402,000 trips in 1985. This level of service was about three times the number of flights scheduled in 1975, which totaled 794,000. On the average, therefore, this would represent a significant improvement in service to small communities. A noncompetitive fleet of 466 aircraft was required for this portion of the market. Total requirements for service to small communities of 512 aircraft were generated only in a noncompetitive simulation. The relatively short-range characteristics of the lower density market are illustrated by the average stage lengths flown.

Basic fleet economic data are shown in Table 4-3. The Net Operating Income (NOI) in 1974 dollars (passenger revenue less total operating cost) showed a substantial loss for the 1985 projected traffic level with the baseline study assumptions.

4.1 Sensitivity Studies

A number of sensitivity studies were conducted in the total U.S. domestic traffic model. Effects generally were measured in both fleet performance and net operating income data.

4.1.1 30 vs. 40-Passenger Aircraft

The first sensitivity study was to analyze the effect of operating an aircraft larger than the 30-passenger study aircraft. Current CAB regulations limit aircraft operating under the Part 298 Exemption for Air Taxi and Commuter Carriers to 7,500 pounds (3,402 kg) or 30 passengers. To illustrate

TABLE 4-3

ECONOMIC RESULTS OF FLEET SIMULATION

1985

Noncompetitive

30-Passenger Turbofan

MARKET CATEGORY	FLEET SIZE	RPM FLOWN (Millions)	PASSENGER REVENUE ($ Millions)	DOC	IOC	NET OPERATING INCOME
				($ Millions)		
COMMUTER CARRIERS	46	334	51.694	48.784	27.398	-24.488
MAJOR CARRIERS	466	6.986	863.627	523.311	457.722	-117.406
TOTALS	512	7.230	915.321	572.095	485.120	-141.894

NOTE: 60% target system load factor

- IOC = 53% Rev
- Standard 1974 CAB fares

the potential of a larger aircraft operating within the same Part 298 regulations, a 40-passenger study aircraft was simulated in competition with the 30-passenger aircraft. Both aircraft were available in the simulation, and a mixed fleet solution was generated. Table 4-4 presents the selected fleet performance data. A total fleet of 400 aircraft would be required if only the 30- and 40-passenger aircraft were available to serve the small communities market as defined in this study. These results were compared with the non-competitive 30-passenger aircraft fleet of 512 vehicles. Note that a composite fleet of 30 and 40-seat vehicles provided 2,136,000 annual aircraft trips (one flight on an airport-pair route), while the 30TF aircraft fleet generated 2,704,000 trips in comparable service. Each of these is appreciably greater than the 1974 minimum requirement of 1,091,000 aircraft trips specified in the traffic demand model.

Although the data on the aircraft were not divided into commuter and major carrier statistics, it is evident that the 30-passenger aircraft was assigned primarily to the commuter routes in the model. The average stage length served by the smaller aircraft was 93 statute miles (150 km), compared to the commuter average stage of 105 statute miles (169 km) shown in Table 4-2. The 40-passenger aircraft was the better selection on the majority of routes, and the average stage length was 164 statute miles (264 km) compared with 161 statute miles (259 km) as shown in Table 4-2.

Fleet economic results are presented in Table 4-5, which show the advantage of incorporating a 40-seat aircraft for a mixed fleet operation. The 30-seat aircraft generated a negative net operating income. However, the 40-passenger aircraft showed a positive net income, resulting in less negative results than the 30-passenger fleet alone.

TABLE 4-4

COMPETITIVE FLEET PERFORMANCE STATISTICS

1985

30 and 40 Passenger Turbofan

Part 298 Payload Exemption

AIRCRAFT	FLEET SIZE	AIRCRAFT TRIPS (Thousand)	AVERAGE STAGE (St.Mi.)	AVERAGE BLOCK SPEED (MPH)	AIRCRAFT UTILIZATION (Hr/Yr)	SYSTEM LOAD FACTOR (%)
30 Passenger	60	409	93	233	2,661	40.1
40 Passenger	340	1,727	164	297	2,804	59.8
TOTAL	400	2,136	157	-	-	58.0

NOTE: 60% Fleet Load Factor target

-40 passenger aircraft costs on comparable basis with 30-passenger and assuming both operate with same payload exemptions as Part 298 of Federal Regulations.

- The physical and economic characteristics of the 40-passenger turbofan aircraft are tabulated in the original medium density study.

TABLE 4-5

COMPETITIVE FLEET ECONOMIC RESULTS

1985

30 and 40 Passenger Turbofan

Part 298 Payload Exemption

AIRCRAFT	FLEET SIZE	RPM FLOWN (Millions)	PASSENGER REVENUE ($ Millions)	DOC ($ Millions)	IOC	NET OPERATING INCOME
30 Passenger	60	446	73.728	62.862	39.076	- 28.210
40 Passenger	340	6,784	841.608	391.530	446.052	4.026
TOTAL	400	7,230	915.336	454.392	485.128	- 24.184

NOTE: 60% Fleet Load Factor, IOC 53% of Revenue, Standard CAB Fare

-40 passenger aircraft costs on comparable basis with 30 passenger and assuming both operate with same payload exemptions as Part 298 of Federal Regulations.

4.1.2 Effect of Higher Growth Rates - Commuter Network

A second sensitivity study was conducted with the baseline 30-passenger turbofan-powered aircraft fleet. Various growth rates were used for that part of the model representing commuter carriers. The baseline growth rate was 2 percent as noted in Table 4-2. Recently, the commuter market has grown rapidly. The effect of higher growth rates on the baseline commuter market is presented in Table 4-6. Annual growth rates up to 12 percent were investigated for only the commuter segment of the small community traffic demand model.

The number of routes in the model was constant. The RPM increased directly with the annual growth rates. Annual trips, fleet size, and load factor did not increase at the same rate. The basic model contained demand elements with low to high relative travel densities and a minimum number of trips required in each element. A six-fold increase in projected traffic only reduced the negative net operating income by $8 million because of the minimum frequency service requirement.

4.1.3 Effect of Reductions in Maneuver Time

The effect of savings in aircraft maneuver time was investigated as a third sensitivity area. In the baseline operation the aircraft block time function has the form of a slope/intercept equation. It is expressed as

$$\text{Block Time} = 0.20 + .0022 \times \text{Range},$$

with time in hours and range in statute miles. The constant of 0.20 hour represents an average amount on each flight which accounts for both ground and airborne maneuver times on takeoff and landing. A small sample of operating data which illustrated ground maneuver time from Frontier Airlines is presented in Table 4-7.

C.2

TABLE 4-6

EFFECT OF HIGHER GROWTH RATES
ON THE COMMUTER MARKET

1985

Noncompetitive
30-Passenger Aircraft

ANNUAL GROWTH RATES (%)	REVENUE PASSENGER MILES (Millions)	ANNUAL AIRCRAFT Trips (Thousands)	FLEET SIZE	SYSTEM LOAD FACTOR (%)	PASSENGER REVENUE ($ Million)	NET OPERATING INCOME ($ Million)
2 (Basic)	334	302	46	37.2	51.694	- 24.488
5	460	317	49	48.3	71.109	- 18.082
8	604	376	58	54.3	96.941	- 16.411
12	900	504	79	59.1	144.625	- 16.400

NOTE: (1) 60% target system load factor
(2) IOC 53% of revenue
(3) CAB standard fares - 1974 levels

TABLE 4-7

TYPICAL CV-580 GROUND MANEUVER TIMES

FRONTIER AIRLINES - 1975

Selected Airports

CV-580 Average Times - Minutes	Alamosa, Colorado	Colorado Springs, Colorado	Salina, Kansas	Billings, Montana
From Landing to Gate	3	4	2	2
From Gate to Takeoff	3	5	3	5
Total Ground Maneuver	6	9	5	7

The maneuver time constant for the 30-passenger study aircraft is 12 minutes. This included ground times similar to those in Table 4-7 plus air maneuver on arrival or departure from the airport. An assumption was made that about one-half of ground maneuver time could be saved. This was assumed to result from better layouts of runway entrances and exists and taxiways. This would allow the aircraft to enter or leave runways and proceed to the gate area with appreciable time savings.

Another assumption was made that the same amount of time could be achieved in air maneuver time. This saving was created by assuming dedicated runways and/or separation of traffic in the terminal pattern.

These savings in time were incorporated in a block time versus maneuver time as a function of range graph for the 30-passenger study aircraft as shown in Figure 4-1. The effect of savings in block time on direct operating trip costs is shown in Figure 4-2. Note that a savings of 4 minutes resulted in a reduction of trip DOC of about 7 percent at 150 nautical miles (278 km),

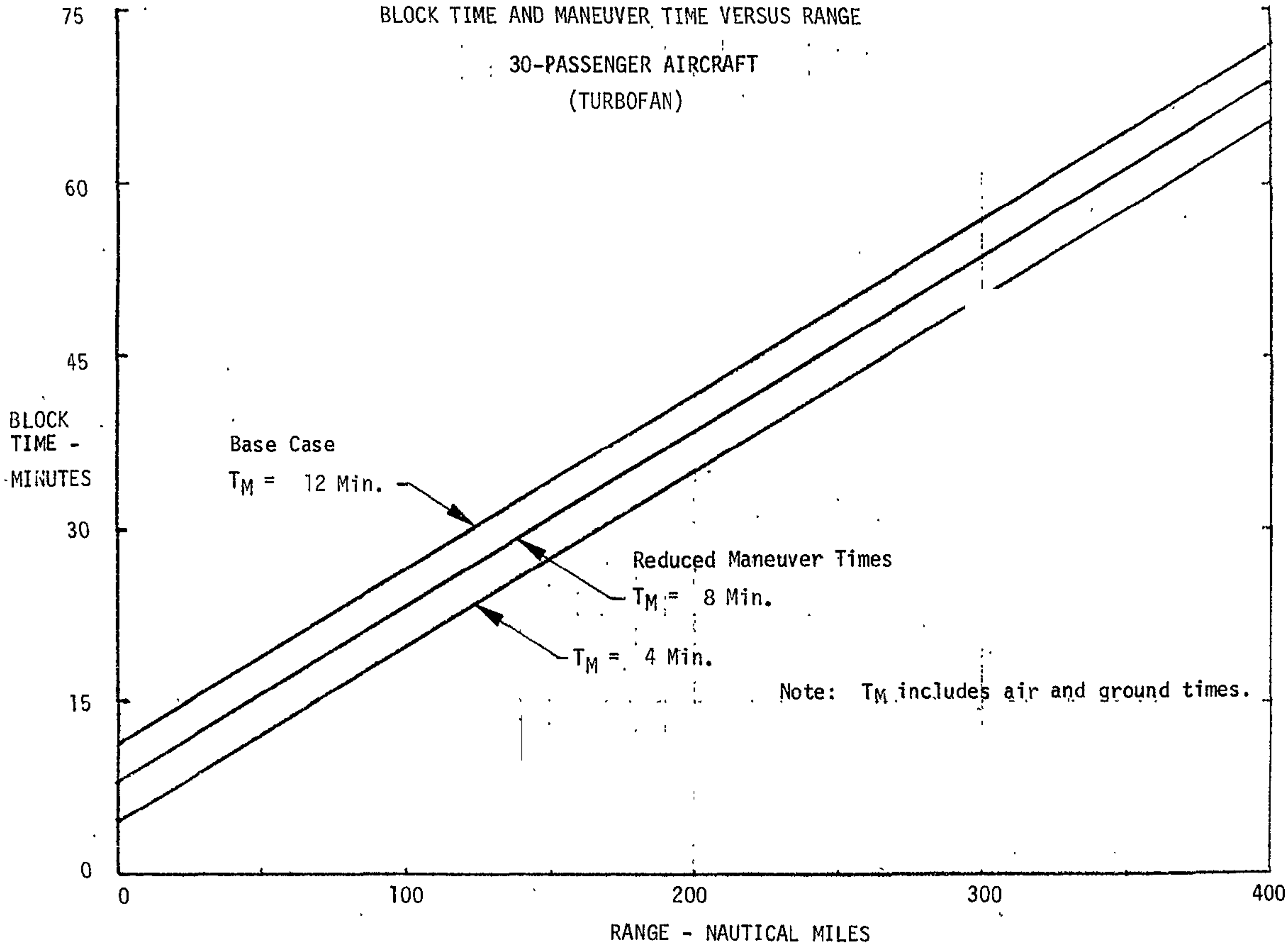

BLOCK TIME AND MANEUVER TIME VERSUS RANGE
30-PASSENGER AIRCRAFT
(TURBOFAN)
BLOCK
TIME -
MINUTES
75
60
45
30
15
0
0
100
200
300
400
RANGE - NAUTICAL MILES
Base Case
T_M = 12 Min.
Reduced Maneuver Times
T_M = 8 Min.
T_M = 4 Min.
Note: T_M includes air and ground times.

FIGURE 4-1

DIRECT OPERATING COST AND MANEUVER TIME VERSUS RANGE

30 PASSENGER AIRCRAFT
(TURBOFAN)

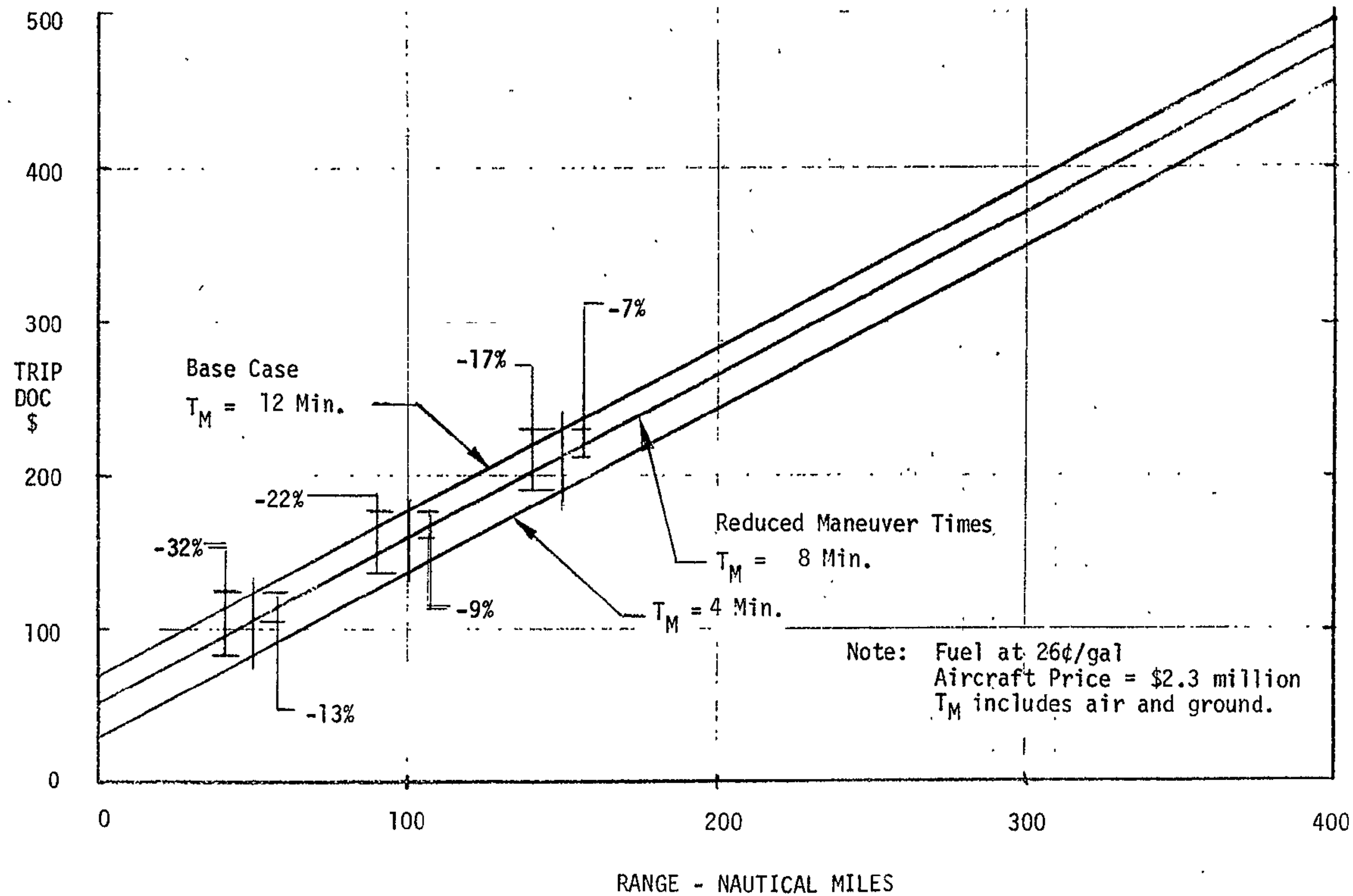


FIGURE 4-2

9 percent at 100 nautical miles (185 km), and 13 percent at 50 nautical miles (93 km). These numbers illustrate the importance of time savings in flights of short duration.

The effects of these savings in aircraft maneuver time have been imposed on the baseline fleet solution. Table 4-8 contains data to measure these effects. For example, block speed (average for the fleet) is increased, the fleet size is reduced about 19 percent, and the net operating income is improved by about 80 percent if the full amount of the reductions were realized. However, the net operating income (NOI) is still negative. This analysis was applied only to the major carriers.

4.1.4 Effect of Fare Increases

Another simulation was conducted on the baseline 30-passenger fleet to measure the effect of fare increases. Figure 4-3 contains a plot of fleet net operating income as a function of passenger fare levels. The baseline result is shown for the CAB Class 7 fare as a negative NOI of about $141 million. This figure represented the NOI for the total fleet, both commuter and major carriers. The operating income figures also are shown separately. The effect of increases in the passenger fares is shown to a value of plus 20 percent. Because of the low load factors achieved in the commuter section of the market, negative incomes are encountered as shown to a plus 25 percent fare increase. However, if the major carriers were considered singly, a breakeven NOI was achieved at a fare increase of about 13 percent. The effect of reduced maneuver times is shown on the NOI trend for major carriers. The amount of savings in time was four minutes or 30 percent of the total maneuver time. With these conditions applied, the breakeven NOI was achieved at a fare increase of about 8 percent above the basic fare level used.

TABLE 4-8

FLEET PERFORMANCE VERSUS MANEUVER TIME

MAJOR CARRIERS - 1985

30-Passenger Aircraft

MANEUVER TIME (Minutes)	AVERAGE BLOCK SPEED (MPH)	FLEET SIZE	AIRCRAFT UTILIZATION (Hr/Yr)	NET OPERATING INCOME ($ Millions)
12	295	466	2,799	- 117.406
8	329	423	2,763	- 78,310
4	373	378	2,728	- 23.138

NOTE: (1) Maneuver includes taxi in/out and takeoff/landing times.

(2) Average block speed at 161 statute miles.

(3) Cost data for turbofan aircraft.

(4) Typical ground maneuver time for Frontier Airlines is 6 to 9 minutes.

NET OPERATING INCOME VERSUS PASSENGER

FARE LEVELS - 1985

30-PASSENGER TURBOFAN

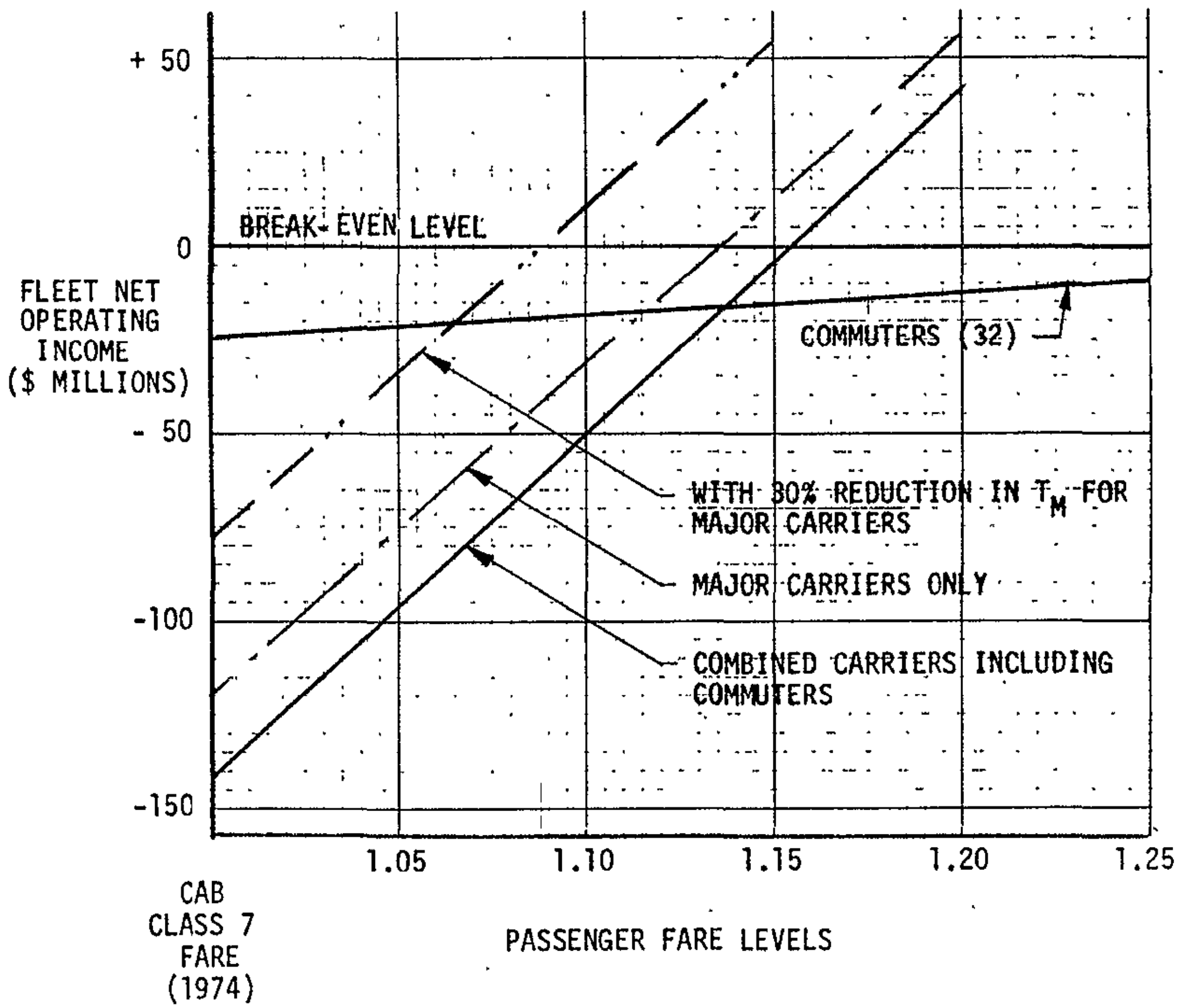


FIGURE 4-3

The base fare yield equation used in this study was the same as used in the prior NASA Medium Density Study. The equation was

$$\text{Yield} = 8.85813 + .07013 \times R$$

with yield in dollars and R in statute miles. This function was calibrated to June 1974 yields for local service airlines. It included 5 percent allowance for freight and express cargo. The yield was intended to represent an average for the market studied.

4.1.5 Effect of Reductions in IOC

A fifth sensitivity investigation involved potential reductions in indirect operating costs (IOC). Data for this was derived from the NASA short-haul economics study (Reference 3). Table 4-9 reveals the relative distribution of IOC items for all local service airlines and Frontier Airlines for comparison. Note that aircraft and traffic servicing accounts for half of the IOC. Typical expense items included in this category are baggage handling at the airport terminal, passenger check-in and boarding, and flight planning and control. Expenses occur at both ends of a trip as passengers enplane or deplane. Promotion and sales is an obvious expense and needs no particular explanation. Passenger service expenses are on-board expenses and include food, beverage, cabin attendants and administrative costs. The other items are self-explanatory as general business terms.

A comparison of IOC distributions among domestic trunk and local service carriers is presented in Table 4-10. Of particular interest is the comparison of aircraft and traffic service expense. This item for trunk carriers is 38.4 percent of total IOC. This lower percentage compared with local carrier may reflect the greater automation in the area of traffic servicing.

TABLE 4-9

INDIRECT OPERATING COSTS DISTRIBUTION

Local Service Airlines Compared
with Frontier Airlines

CAB DATA - 1973

COST ITEMS	PERCENT DISTRIBUTION All Local Service	PERCENT DISTRIBUTION Frontier Airlines
Aircraft and Traffic Servicing	50.6	49.0
Promotion and Sales	20.3	20.5
Passenger Service	14.2	16.1
General and Administrative	11.0	11.2
Ground Property and Equipment Amortization	4.0	3.2

TABLE 4-10

DISTRIBUTION OF INDIRECT OPERATING EXPENSE

Certificated Carriers

1973

EXPENSE CATEGORY	PERCENT DISTRIBUTION			
	Domestic Trunks		Local Service	
Passenger Service		22.2		14.2
Aircraft and Traffice Service:		38.4		50.6
Aircraft Servicing	16.7		16.7	
Traffic Servicing	19.5		31.9	
Administration	2.2		2.0	
Promotion and Sales		23.2		20.3
General and Administrative		9.1		11.0
Ground Property and Equipment Expense		6.4		3.2
Other		0.7		0.7

An airline comparison of the total aircraft and traffic servicing expense account is contained in Table 4-11. The relative distribution of the expense items for eight airlines again emphasizes the magnitude of traffic servicing expenses. This appeared to be the most likely area for potential reduction in indirect operating expenses.

It was estimated in the NASA short-haul economics study that the application of automation could reduce the cost of traffic servicing and promotion and sales activities. Table 4-12 indicates a total of 4.1 percent savings. This amount was applied to the baseline fleet results with the 30-passenger turbofan aircraft. The application of this IOC savings resulted in an improvement in NOI from negative $142 million to negative $122 million.

4.1.6 Effect of Factors on Choice of Mode

The last sensitivity study in this series included a patronage study involving a traveler choice between auto and local service airline. A Douglas Aircraft patronage model was used to evaluate factors affecting traveler's choice between air and auto. Factors evaluated included:

- Increased flight frequency;
- Reduction of number of stops with attendant reduction in total flight time, and
- Reduction in air fare.

A number of patronage evaluations were conducted with combinations of the following:

- Two stage length - 250 and 400 statute miles (402 and 644 km);
- Two different number of enroute stops (0 to 1 stop for the 250

TABLE 4-11

DISTRIBUTION OF AIRCRAFT AND TRAFFIC SERVICING EXPENSE

LOCAL SERVICE CARRIERS

1973

AIRLINE	PERCENT DISTRIBUTION		
	AIRCRAFT SERVICING	TRAFFIC SERVICING	SERVICING ADMINISTRATION
ALLEGHENY	35	63	2
FRONTIER	24	69	7
HUGHES AIRWEST	35	60	5
NORTH CENTRAL	28	65	7
OZARK	38	54	8
PIEDMONT	34	65	1
SOUTHERN	34	61	5
TEXAS INTERNATIONAL	33	63	4

TABLE 4-12

EFFECT OF POTENTIAL SAVINGS IN IOC

Automation may reduce IOCs in:

Traffic Servicing	3.6%
Promotion and Sales	.5%
Net Savings	4.1%

This savings applied to noncompetitive fleet results with the 30-passenger turbofan shows the following:

	Passenger Revenue	DOC	IOC Value	IOC Percent of Revenue	Net Operating Income
BASE	915.321	572.095	485.120	53	- 141.894
	(With IOC savings of $19.889)		465.231	51	- 122.005

* All values in $ Millions

statute mile stage length and one or two stops for the 400 statute mile stage length);

- Two air fare levels (representing a selected local service airline fare and 80 percent of airline fare);
- Four service frequencies (representing one, two, or three flights per day, plus an average 45 minute wait for a flight with a dial-a-plane service).

General data and assumptions were as follows:

- Auto distance of 325 statute miles (523 km) corresponded to the air distance of 250 statute miles (402 km).
- Auto distance of 475 statute miles (764 km) corresponded to the air distance of 400 statute miles (644 km).
- Flight times corresponded to the CV-580 times at the same stage lengths.
- Fares were actuals for Frontier CV-580 service in May 1975.
- An enroute stop increased trip time by 25 minutes.
- The difference between desired and actual departure times was 300 minutes for one flight per day, 150 minutes for two flights, 100 minutes for three flights, and 45 minutes for dial-a-plane service.

Results of the analysis are presented in Table 4-13. The percentage of travelers selecting air ranges from 11 percent to 59 percent. Reductions in air fare showed the most dramatic increase in patronage.

Considering the existing fare as nominal, an increase in non-stop flights per day from one to three resulted in a shift in air travelers from 13 to 25 percent in 250 statute miles (402 km) and from 22 to 38 percent of

TABLE 4-13

AIR VERSUS AUTO TRAVEL

FACTORS AFFECTING CHOICE OF MODE

Stage Length	Flights per Day	No. of Enroute Stops	Percent Selecting Air: Existing Air Fare	Percent Selecting Air: 80 % of Existing Air Fare
250 miles	1	0	13	20
		1	11	17
	2	0	21	33
		1	18	28
	3	0	25	39
		1	21	32
	Dial-a-Plane	0	31	45
		1	25	39
400 miles	1	1	22	33
		2	19	29
	2	1	33	48
		2	29	42
	3	1	38	53
		2	33	47
	Dial-a-Plane	1	43	59
		2	37	53

those choosing one-stop service at 400 statute miles (644 km) travel distance. The Dial-A-Plane service attracted riders because of the reduced waiting time attributed to this concept. At both travel distances, an increase in flight frequency resulted in the greater increase in air patronage.

5.0 SIMULATION ON SELECTED FRONTIER AIRLINES NETWORK

A base case with the 30-passenger turbofan aircraft was constructed in the Frontier traffic demand model. This was a noncompetitive evaluation of the study aircraft. Similar evaluations were conducted for the 30-passenger turboprop and the 40-passenger turbofan aircraft. A competitive operational simulation also was made with the 30-passenger study turbofan (30 TF) and three contemporary aircraft. These were the Short SD3-30, the Falcon 30, and the deHavilland of Canada DHC-7. Basic characteristics of these aircraft were included in the previous NASA Medium Density Study. A summary of pertinent characteristics employed for the competitive simulation is presented in Table 5-1.

TABLE 5-1

SIMULATION AIRCRAFT CHARACTERISTICS

AIRCRAFT	SEATS	RANGE N.MI. (KM)	BLOCK TIME FUNCTION HR., N.MI.	COMPUTED DOC FUNCTION $, N.MI.
30 TF	30	563 (1045)	.2 + .00245 R	56.27 + 1.222 R
40 TF	40	850 (1574)	.2 + .00245 R	84.35 + .998 R
SD-3-30	30	320 (593)	.2 + .0051 R	39.83 + 1.713 R
Falcon 30	30	780 (1445)	.2 + .00246 R	73.15 + 1.325 R
DHC-7	48	768 (1422)	.2 + .0051 R	57.13 + 2.181 R

The computed DOC function equations represent a modification of the DOC equations used in the original Medium Density study. The statistical CAB data on existing airline operations that was used in the NASA Short-Haul Economics study to generate cost functions pertinent to short-haul aircraft were applied to the turbofan study and the competitive aircraft (Appendix A-4). The selection of modified equations for the three competitive aircraft was based on the more detailed engine and airframe maintenance evaluations of the Short-Haul Economics Study. In the original Medium Density Study, the cost equations for the three competitive aircraft were based on company brochures and data published in technical journals. Thus, the statistical basis for computing DOC functions with the modified methods was assumed appropriate for the turbofan and competitive aircraft.

In addition to the simulations conducted in this demand model, fleet planning sensitivities were studied with the Douglas Airline Schedule Planning and Evaluation Model. These included itinerary scheduling and effects of increased schedule frequencies on load factor and daily utilization.

Some general statistics for Frontier Airlines are included as Table 5-2. The network for simulation was drawn from those airports served by the CV-580 and Twin Otter aircraft.

TABLE 5-2

BASIC FRONTIER AIRLINES AIRPORT DATA
1975

TOTAL AIRPORTS SERVED	92
NONCOMPETITIVE	46
COMPETITIVE	46
FRONTIER CONVAIR 580 SERVICE	75*
FRONTIER TWIN OTTER SERVICE	18*
MINIMUM RUNWAY LENGTH (FT) (STILLWATER, OKLA.)	5,002 (1525 METERS)
MAXIMUM RUNWAY LENGTH (FT) (AMARILLO, TEXAS)	13,500 (4115 METERS)
INSTRUMENTED LANDING SYSTEMS (ILS)	77
AIRPORTS WITHOUT ILS	15

*TRAFFIC MODEL NETWORK DRAWN FROM THESE ROUTES

A general impression of Frontier Airlines terminal operation may be derived from data contained in Table 5-3. For example, Billings is a terminus for flights. Aircraft are serviced with fuel, food and beverage and have needed line maintenance checks and service during daytime or overnight periods. At the other stations, the number of personnel corresponds with the flight departure activities. Cargo administration is provided by Frontier personnel. Fueling and catering are contracted. The major tasks shared by Frontier employes involves processing passengers and baggage through the terminals and on/off the aircraft.

5.1 Base Case Fleet Performance

A noncompetitive operational simulation on the Frontier network with the 30-passenger turbofan and turboprop aircraft is summarized in Table 5-4. Note that the basic performance characteristics of both the turbofan and turboprop are identical. Economic characteristics are different (see Appendix A-4). The turboprop powered fleet has an NOI of -$5,000 because of lower engine prices, lower fuel consumption, and lower flight crew costs. The -$5,000 NOI contrasts with the fleet NOI of -$5,703,000 for the turbofan configuration. The average stage length of 125 statute miles (202 km) compares with the average of 161 statute miles (259 km) for major carriers in the total domestic market. The shorter average stage length for the selected Frontier network results from inclusion of the Twin Otter routes. Other performance statistics are comparable with the total domestic market results.

Another version of the base case involved use of the 40-passenger turbofan aircraft. Fleet statistics are shown in Table 5-5. The fleet size is 17 compared with 24 of 30-passenger capacity. The system load factor averages slightly under the target of 60 percent.

TABLE 5-3

TERMINAL OPERATIONS DATA

SELECTED FRONTIER AIRLINES AIRPORTS - 1975

ITEMS	ALAMOSA, COLORADO	COLORADO SPRINGS, COLORADO	BILLINGS, MONTANA	SALINA, KANSAS
NUMBER OF EMPLOYEES	6	16	29	7
737 DEPARTURES/DAY	0	3.0	4.0	0
CV-580 DEPARTURES/DAY	4.2	7.3	4.6	3.0
PASSENGER RESERVATIONS	FL	R	R	FL
CARGO ADMINISTRATION	FL	FL	FL	FL
AIRCRAFT FUELING	C	C	C	C
AIRCRAFT MAINTENANCE CHECK	N.P.	N.P.	FL	N.P.
FOOD/BEVERAGE CATERING	N.P.	N.P.	C	N.P.
BAGGAGE/PASSENGER PROCESSING	FL	FL	FL	FL

NOTES: FL - Performed by Frontier employees

R - Remote telephone to central office

C - Contract Service

N.P. - Not performed

TABLE 5-4

BASE CASE FLEET PERFORMANCE

1985

30-PASSENGER TURBOFAN AND TURBOPROP

FLEET SIZE	AIRCRAFT TRIPS (THOUSANDS)	AVERAGE STAGE (ST. MI)	AVERAGE BLOCK SPEED (MPH)	AIRCRAFT UTILIZATION (HR/YR)	SYSTEM LOAD FACTOR (%)
24	142	125	268	2723	59.7

PASSENGER REVENUE ($ MILLIONS)	AIRCRAFT TYPE	DOC ($ MILLIONS)	IOC ($ MILLIONS)	NET OPERATING INCOME ($ MILLIONS)
44.681	TURBOFAN	26.783	23.681	-5.783
	TURBOPROP	21.005	23.681	-0.005

NOTE: (1) NONCOMPETITIVE SIMULATION

(2) TRAFFIC STATISTICS PROJECTED FROM 1974 OAG

(3) TARGET SYSTEM LOAD FACTOR = 60%

(4) IOC 53% REVENUE

TABLE 5-5

40-PASSENGER TURBOFAN FLEET PERFORMANCE

1985

FLEET SIZE	AIRCRAFT TRIPS (THOUSANDS)	AVERAGE STAGE (ST. MI.)	AVERAGE BLOCK SPEED (MPH)	AIRCRAFT UTILIZATION (HR/YR)	SYSTEM LOAD FACTOR (%)
17	109	125	267	2721	58.6

PASSENGER REVENUE ($ MILLIONS)	DOC ($ MILLIONS)	IOC	NET OPERATING INCOME
44.681	20.963	23.681	0.037

NOTES: (1) NONCOMPETITIVE SIMULATION

(2) TRAFFIC STATISTICS PROJECTED FROM 1974 OAG

(3) TARGET SYSTEM LOAD FACTOR = 60%

(4) IOC 53% REVENUE

The most notable contrast, however, is in the NOI which is slightly positive at $37,000 for the year. This illustrates the economy of scale of the 40 compared with the 30-passenger aircraft. Annual trips were 109,000 compared with 142,000, but are still adequate in terms of service frequency.

5.1.1 Competitive Fleet Simulations

A series of competitive fleet operational simulations were made with various combinations of aircraft. The first competitive analysis was done with four aircraft including the 30 TF. The contemporary aircraft included in the competition were the SD 3-30, Falcon 30, and DHC-7. Of the four aircraft available, the 30 TF and DHC-7 provided the least-cost service, sharing the market as shown in Table 5-6. The 30 TF, in its share of Frontier traffic, flew the longer stages where its higher speed was more economic. The DHC-7 was chosen on the shorter routes. Each aircraft operated at or near the target system load factor. Economic fleet results are listed in Table 5-7. Note that each aircraft generated a negative NOI.

Another competitive evaluation was made with only the 30 TF and the SD3-30 available for service. On only a few of the shortest routes the SD3-30 was selected, as revealed in Table 5-8. Of the total fleet of 25 aircraft, 23 were the 30 TF. A marked difference in block speed resulted from the slower cruise speed of the SD3-30 and its assignment to very short routes.

Fleet economic data are presented in Table 5-9. The dominance of the 30 TF is shown by its share of the RPM generated. Although the SD3-30 showed a positive NOI, its share of the market as a least-cost aircraft was very small. Thus, total fleet results showed a negative NOI.

TABLE 5-6

COMPETITIVE FLEET PERFORMANCE

1985

AVAILABLE AIRCRAFT: 30 TF, FALCON 30, DHC-7, SD3-30

AIRCRAFT TYPE	FLEET SIZE	AIRCRAFT TRIPS (THOUSANDS)	AVERAGE STAGE (ST. MI)	AVERAGE BLOCK SPEED (MPH)	AIRCRAFT UTILIZATION (HR/YR)	SYSTEM LOAD FACTOR (%)
30 TF	16	80	163	296	2,778	59.6
DHC-7	8	39	78	143	2,772	60.0
TOTAL	24	119	125	--	--	59.7

TARGET SYSTEM LOAD FACTOR = 60%

TABLE 5-7

COMPETITIVE FLEET ECONOMICS

1985

AVAILABLE AIRCRAFT: 30 TF, FALCON 30, DHC-7, SD3-30

AIRCRAFT TYPE	FLEET SIZE	RPM FLOWN (MILLIONS)	PASSENGER REVENUE ($ MILLIONS)	DOC	IOC	NET OPERATING INCOME
				($ MILLIONS)		
30 TF	16	230	28.618	18.117	15.167	-4.666
DHC-7	8	88	16.063	7.985	8.513	- .435
TOTAL	24	318	44.681	26.102	23.680	-5.101

NOTE: TARGET SYSTEM LOAD FACTOR = 60%
IOC 53% REVENUE

TABLE 5-8

COMPETITIVE FLEET PERFORMANCE

1985

AVAILABLE AIRCRAFT: 30 TF, SD3-30

AIRCRAFT TYPE	FLEET SIZE	AIRCRAFT TRIPS (THOUSANDS)	AVERAGE STAGE (ST. MI)	AVERAGE BLOCK SPEED (MPH)	AIRCRAFT UTILIZATION (HR/YR)	SYSTEM LOAD FACTOR (%)
30 TF	23	133	132	274	2,731	59.7
SD3-30	2	9	37	80	2,697	60.0
TOTAL	25	142	125	--	--	59.7

TARGET SYSTEM LOAD FACTOR = 60%

TABLE 5-9

COMPETITIVE FLEET ECONOMICS

1985

AVAILABLE AIRCRAFT: 30 TF, SD3-30

AIRCRAFT TYPE	FLEET SIZE	RPM FLOWN (MILLIONS	PASSENGER REVENUE ($ MILLIONS)	DOC	IOC	NET OPERATING INCOME
				($ MILLIONS)		
30 TF	23	311	42.766	25.896	22.666	-5.796
SD3-30	2	6	1.915	0.881	1.015	+ .019
TOTAL	25	317	44.681	26.777	23.681	-5.777

TARGET SYSTEM LOAD FACTOR = 60%

IOC 53% REVENUE

5.1.2 Summary of Operational Simulations

A summary of pertinent results for the operational simulations in the Frontier traffic model is contained in Table 5-10. The 30-passenger turbofan study aircraft plus either the SD3-30 or the DHC-7 resulted in a negative net operating income (NOI). The best mixed fleet was the 30 TF plus the DHC-7. The 40-passenger turbofan was the more attractive aircraft of all of the simulations. It was the only aircraft in which the total fleet NOI was positive. A minimum average of seven weekly round trips per route was required to be comparable with the 1974 schedule. All of the fleet simulations generated 13, 14, or 15 round trips. Thus, service provided in 1985 was generally twice that required as a minimum level of service.

A number of factors were evaluated for effectivity in improving the net operating income or providing better service. Table 5-11 shows what some of these factor improvements could do if they were applicable to the Frontier base case. If a shortened IFR approach were applicable to one-fourth of annual trips, a reduction in block time and DOC would result. A cost benefit of $885,000 resulted as shown. Similarly, reductions in baggage and passenger processing were estimated to reduce IOC by about 3.6 percent. This benefit was $853,000. Another saving in maneuver time on one-fourth of annual trips resulted in a reduction of $518,000 in DOC.

A change in revenue of 15 percent increase was the most dramatic change evaluated. This much increase in income alone, plus the other savings, increased net operating income by over $8 million as indicated in Table 5-11.

TABLE 5-10

SUMMARY OF COMPETITIVE FLEET SIMULATIONS

1985

FLEET COMPOSITION	FLEET SIZE	AVERAGE WEEKLY ROUND-TRIPS PER ROUTE		ANNUAL NET OPERATING INCOME ($ MILLIONS)
		MINIMUM REQUIRED	ACTUAL PROVIDED	
30 TF	24	7	15	-5.783
30 TP	24	7	15	-0.005
40 TF	17	7	14	0.037
30 TF/DHC-7	24	7	13	-5.101
30 TF/SD3-30	25	7	15	-5.777

NOTE: 91 AIRPORT-PAIR ROUTES IN MODEL
TARGET SYSTEM LOAD FACTOR = 60%
IOC 53% OF REVENUE

TABLE 5-11

SENSITIVITY OF COST/REVENUE BENEFITS

30-PASSENGER TURBOFAN

NONCOMPETITIVE

1985

	COST/REVENUE BENEFITS	DOC	IOC	NET OPERATING INCOME
		($ MILLION)		
BASE CASE	--	26.783	23.681	-5.783
SHORTENED IFR APPROACH DISTANCES (1)	-.885	25.898	23.681	-4.898
BAGGAGE AND PASSENGER PROCESSING (2)	-.853	25.898	22.828	-4.045
15% FARE INCREASE	+6.702	25.898	22.828	+2.657
GROUND MANEUVER TIME REDUCTION (3)	-.518	25.380	22.828	+3.175

NOTES: (1) ASSUMING $24.94 SAVINGS ON 1/4 OF ANNUAL TRIPS
(2) REDUCTION OF 3.6% FROM AUTOMATION OF PASSENGER AND BAGGAGE HANDLING
(3) REDUCTION OF 4.0 MINUTES IN GROUND MANEUVER TIME ON 1/4 OF ANNUAL TRIPS

5.2 Sensitivity Studies - Selected Frontier Network

Two types of operational sensitivity studies were conducted. The first was an evaluation of variations from the 60 percent system load factor used as a target for all of the previous simulations. The second sensitivity study was an evaluation of the impact of variations in annual aircraft utilization rates. Each of these sensitivity studies was evaluated for effects on fleet size, annual aircraft trips, and net operating income.

5.2.1 Effect of Load Factor Variations

In the Frontier Airlines selected network simulation with a competitive fleet, a 50 percent and a 70 percent system load factor were tested. Table 5-12 presents fleet performance statistics and Table 5-13 the economic results of simulation with a 50 percent system load factor. Fleet composition was the same as at 60 percent, except the number of aircraft in the fleet was greater, 28 rather than 24. The annual aircraft trips also increased, from 119,000 to 141,000; however, the NOI decreased.

Another simulation was conducted at a 70 percent system load factor. Again, the fleet composition was the same, with only 21 aircraft required. Aircraft trips dropped to 103,000 for the year. These results are summarized in Table 5-14. Fleet economic results are presented in Table 5-15. The net operating income at a 70 percent system load factor was markedly improved, with the DHC-7 showing a positive NOI of $706,000. However, the 30 TF NOI was sufficiently negative to result in a fleet NOI of -$1,612,000.

A recap of the competitive fleet results of the three system load factors is included as Table 5-16. Since each fleet satisfied the same RPM demand, the revenue was constant at $44,681,000. Total operating cost was a

TABLE 5-12

COMPETITIVE FLEET PERFORMANCE

1985

50% LOAD FACTOR

AVAILABLE AIRCRAFT: 30 TF, FALCON 30, SD3-30, DHC-7

AIRCRAFT TYPE	FLEET SIZE	AIRCRAFT TRIPS (THOUSANDS)	AVERAGE STAGE (ST. MI)	AVERAGE BLOCK SPEED (MPH)	AIRCRAFT UTILIZATION (HR/YR)	SYSTEM LOAD FACTOR (%)
30 TF	19	94	163	296	2,780	50.0
DHC-7	9	47	78	143	2,772	50.0
TOTAL	28	141	125	--	--	50.0

TABLE 5-13

COMPETITIVE FLEET ECONOMICS

1985

50% LOAD FACTOR

AVAILABLE AIRCRAFT: 30 TF, FALCON 30, SD3-30, DHC-7

AIRCRAFT TYPE	FLEET SIZE	RPM FLOWN (MILLIONS)	PASSENGER REVENUE ($ MILLIONS)	DOC	IOC	NET OPERATING INCOME
				($ MILLIONS)		
30 TF	19	230	28.618	21.544	15.167	-8.093
DHC-7	9	88	16.063	9.582	8.513	-2.032
TOTAL	28	318	44.681	31.126	23.680	-10.125

IOC = 53% OF REVENUE

TABLE 5-14

COMPETITIVE FLEET PERFORMANCE

1985

70% LOAD FACTOR

AVAILABLE AIRCRAFT: 30 TF, FALCON 30, SD3-30, DHC-7

AIRCRAFT TYPE	FLEET SIZE	AIRCRAFT TRIPS (THOUSANDS)	AVERAGE STAGE (ST. MI)	AVERAGE BLOCK SPEED (MPH)	AIRCRAFT UTILIZATION (HR/YR)	SYSTEM LOAD FACTOR (%)
30 TF	14	70	163	294	2,776	68.7
DHC-7	7	33	78	143	2,772	70.0
TOTAL	21	103	125	--	--	69.0

TABLE 5-15

COMPETITIVE FLEET ECONOMICS

1985

70% LOAD FACTOR

AVAILABLE AIRCRAFT: 30 TF, FALCON 30, SD3-30, DHC-7

AIRCRAFT TYPE	FLEET SIZE	RPM FLOWN (MILLIONS)	PASSENGER REVENUE ($ MILLIONS)	DOC	IOC	NET OPERATING INCOME
				($ MILLIONS)		
30 TF	14	230	28.618	15.769	15.167	-2.318
DHC-7	7	87	16.063	6.844	8.513	+.706
TOTAL	21	317	44.681	22.613	23.680	-1.612

IOC = 53% OF REVENUE

TABLE 5-16

SUMMARY EFFECTS OF LOAD FACTOR

VARIATIONS - 1985

AVAILABLE AIRCRAFT: 30 TF, SD3-30, F30, DHC-7

AIRCRAFT SELECTED: 30 TF, DHC-7

LOAD FACTOR (%)	FLEET SIZE	TOTAL OPERATING COST ($ MILL)	NET OPERATING INCOME ($ MILL)
50	28	54.786	- 10.125
60	24	49.782	- 5.101
70	21	46.293	- 1.612

function of fleet size, thus the smaller fleet showed the best economic solution, even though it was a negative NOI.

5.2.2 Effect of Variations in Aircraft Annual Utilization

A final simulation exercise was conducted in the Frontier demand model to evaluate the effect of variations in the annual utilization rates achieved by the 30 TF study aircraft. Table 5-17 shows selected data with -20 percent, -10 percent, and +10 percent changes in utilization. The first immediate effect was the direct change in fleet size. A reduction in utilization resulted in an increase in fleet size. The resultant increase in fleet price is noted in the second line of data. The same number of trips and RPM applied to each fleet, hence revenue remained the same for all fleets. Since the amount of depreciation varied only slightly, the DOC remained essentially the same, and net operating income was unchanged with changes in utilization. The significant change was in the fleet price and hence the investment base of the fleet. The primary significance of high utilization rates to an airline is the resultant minimum level of capital investment required in the aircraft fleet. The effect also is to maximize the return on investment with a given cost and revenue level.

TABLE 5-17

VARIATIONS IN ANNUAL UTILIZATION

1985

30-PASSENGER TURBOFAN

ITEM	BASE CASE UTILIZATION	-20% UTILIZATION	-10% UTILIZATION	+10% UTILIZATION
FLEET SIZE	24	30	27	21
FLEET PRICE ($ MILLIONS)	55.2	69.0	62.1	48.3
TOTAL AIRCRAFT TRIPS (THOUSANDS)	142	142	142	142
UTILIZATION (HR/YR/ACFT)	2,723	2,178	2,451	2,995
AIRCRAFT PRODUCTIVITY (MILL, RPM/YR/ACFT)	13.08	10.47	11.77	14.39

6.0 APPLICATION OF AIRLINE SCHEDULE PLANNING AND EVALUATION MODEL IN SELECTED FRONTIER AIRLINE NETWORK

An April 1975 schedule for Frontier Airlines provided a base for planning a schedule with the 30-passenger turbofan study aircraft. CAB data for 1973 was projected for origin and destination city-pairs to a 1985 level. The rate averaged 5.24 percent per year. Routes selected for the itinerary planning network were those on which CV-580 and Twin Otter service was provided. Routes selected also were limited to the 400 statute mile (644 km) limit and 300 passengers per day total travel. This selection resulted in a planning model with 46 airports and 54 airport-pair routes.

A basic itinerary was planned with the 30TF study aircraft. The 54 routes were scheduled with between one and eight round trips per day, comparable to the 1975 schedule. A modified itinerary was then adopted which increased the minimum service to two daily round trips. These data are presented in Table 6-1.

Fleet performance statistics are contained in Table 6-2. The basic mission was to provide 7,101,000 passenger miles per week. A fleet planned for minimum number of aircraft with at least the same service level as 1975 resulted in a total number of 25 aircraft. A target system load factor of 60 percent was achieved as shown, with 1,932 aircraft departures per week. A weighted average stage length of 204 statute miles (328 km) was generated.

The fleet required with the modified itinerary was enlarged to 31 aircraft. The resultant departures were increased as shown. The average stage length decreased reflecting the fact that more departures were offered on the shorter segments in the network. Total passenger miles being held constant resulted in a lower average system load factor of 48 percent as shown

TABLE 6-1

AIRLINE SCHEDULE PLANNING

1985

DISTRIBUTION OF DEPARTURE FREQUENCIES

30 PASSENGER TURBOFAN

DAILY ROUND TRIPS	SEGMENTS INCLUDED IN SCHEDULE (3)	
	Basic Itinerary (1)	Modified Itinerary (2)
1	15	0
2	18	15
3	8	26
4	6	6
5	5	5
6	1	1
7	0	0
8	1	1

NOTES: (1) Itinerary optimized for minimum fleet service
(2) Itinerary adjusted for improved service
(3) 46 airports, 54 city-pair segments

TABLE 6-2

COMPARISON OF MINIMUM AND IMPROVED SCHEDULES

1985

30 PASSENGER TURBOFAN

SCHEDULED ITINERARY	FLEET SIZE	AIRCRAFT DEPARTURES PER WEEK	PASSENGER MILES PER WEEK*	AVERAGE STAGE (St.Mi.)	LOAD FACTOR (%)
Basic	25	1,932	7,101,000	204	60
Modified	31	2,394	7,101,000	170	48

NOTE: (1) 46 airports, 54 city-pair route segments
(2) Aircraft utilization = 7.2 hr/day

*Based on 1973 CAB data projected to 1985 at 5.24 percent average annual growth

The effect of adding aircraft to the fleet to allow selective increases in departure frequency is revealed in Table 6-3. The first two lines of fleet data show the basic and modified itineraries developed in Table 6-1. The next three lines (Mod. 2, 3, and 4) show the resultant fleet size and load factors corresponding to assumed reductions in daily utilization rates. Increases in number of aircraft resulted in decreases in both the daily utilization and the system load factor.

In all of these analyses, the demand was kept constant with no change in RPM. This policy was part of the study simulation ground rules and was extended to the intinerary schedule planning.

TABLE 6-3

EFFECT OF IMPROVED SERVICE ON FLEET OPERATIONS

30 PASSENGER TURBOFAN

SCHEDULED ITINERARY	DAILY UTILIZATION (Hours)	FLEET SIZE	SYSTEM LOAD FACTOR (%)
Basic	7.2	25	60
Modified	7.2	31	48
Mod. 2	7.0	32	46
Mod. 3	6.5	34	44
Mod. 4	6.0	37	41

7.0 CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

In the original medium density study, a market was studied which included traffic densities from 20 to 500 travelers per day to a maximum distance of 800 statute miles (1,288 km). The market included 1985 projected demand data for local service airlines as well as 21 commuter airlines. A competitive evaluation for 1985 was made with an all-jet turbofan fleet. Passenger capacities ranged from 30 to 96 per aircraft. The 30-passenger study turbofan furnished 578,000 trips from a total of 2,202,000 annual aircraft trips at an average load factor of 40.9 percent. The aircraft averaged about 90 statute miles (144 km) in stage length. The number of 30-passenger aircraft was 91 compared with the fleet total of 500 for the entire medium density market. The fleet of 91 generated a net loss of about $36 million for the year 1985.

In this current study of operational factors of air service to small communities, the market was reordered to include daily route densities from 1 to 300 travelers. The distance was a maximum of 400 statute miles (644 km). Thus the lower end of the medium density market was used as a base for the small community market. In addition, data from ten domestic trunk carriers was added to nine local service airlines. Data from 32 commuter airlines completed the small community market.

The addition of more travelers in the market resulted in a 1985 projection of about 40 to 45 million passenger seats demanded at distances up to 400 statute miles (644 km). Inclusion of trunk and commuter schedules resulted in a minimum service requirement of 1,091,000 annual aircraft trips.

Noncompetitive simulation with the 30-passenger turbofan aircraft resulted in fleet requirements of 512 aircraft. A total of 2,704,000 aircraft trips and a net operating loss of about $142 million were generated with this fleet at an average load factor of 58 percent. The average stage distance was 105 statute miles (169 km).

Because of the cost of operations, including indirect costs at a 60 percent target system load factor, the 30-seat aircraft did not generate profitable net operating income with a yield based on the 1974 CAB fare levels. The use of a turboprop configuration resulted in an improved income level, but the total results were still negative with passenger revenue yields slightly less than total operating costs.

If a 40-passenger aircraft were to be operated under the same economic ground rules and the Part 298 exemption as the 30-passenger aircraft, it could serve the upper part of the small community market. At a 60 percent load factor, the 40TF aircraft generated a positive net operating income as a part of an exclusive fleet of 30 and 40-seat study aircraft.

Competition among the 30TF and three contemporary aircraft showed a combination of 30TF and DHC-7 as the least-cost fleet. Net operating income although maximized, was still negative. The generally negative results of all the simulations stemmed from the relatively high operating costs of the 30TF and the requirement to provide service equal to or better than the flights scheduled in 1974. This latter requirement actually resulted in very low (37.2 percent) load factors in the commuter share of the total domestic market as studied.

Savings in maneuver time were shown to be significant with respect to the relatively short average block times achieved by the study aircraft. These savings were important in their impact on direct trip costs and operating income.

Some savings in indirect operating costs were suggested in the NASA short-haul economics study (Reference 3). These savings were applied in this study, but the amount of savings in net operating income was not significant. There did not appear to be very much potential for savings to airlines in this area.

Design and production of either the turbofan or turboprop version of the study aircraft is well within current technology. No current turbofan engine of the right size exists, therefore, adaptation of "off-the-shelf" engines would result in some increases in fuel burned and gross weight of the aircraft, compared with the performance of the study aircraft.

The turbofan engines mounted on the aft fuselage offer the advantages of a clean wing with forward blanking of engine noise on approach to the ground. However, a wing-mounted propulsion system affords more potential for fuselage lengthening in growth versions.

The turboprop was designed for a low-wing configuration similar in plan to the turbofan configuration. The turboprop consumed less fuel and showed greater multistage capability than the turbofan with comparable speed, altitude and range. At payloads of 70 percent and less, the turboprop had 20 to 30 percent greater range capability than the turbofan configuration.

The use of enroute and terminal area navigation could reduce the aircraft flight path distances and corresponding flight times. The deployment and implementation of a microwave landing system could also save time by permitting a shortened multipath curved approach to the landing runway.

RECOMMENDATIONS

Since this study was limited both in depth and scope, there are areas which should be investigated further. For example, the market for air service to small communities should be defined as the total potential for passengers up to a travel distance of 400 statute miles (644 km) and not truncated when growth causes the 300 passengers per route per day to be exceeded. This market should be investigated thoroughly with respect to growth trends and fare structures, particularly in those areas currently served by the commuter airlines and projected to the 1980's

With a broader and more detailed definition of the market, the performance requirements and economic characteristics may be derived for an aircraft best suited to fit the projected market. To meet these requirements and characteristics a design study should determine the appropriate transportation system.

In the airline operations environment, more detailed analyses should be conducted on potential improvements in the use of existing navigation aids. More intensive study should be made of the future impact on operations and costs of MLS, DABS, Data Link, and LORAN systems if utilized by airlines in providing service to small communities.

In the event that more than one size of aircraft were required, the potential shrink/stretch capability of aircraft should be studied. This

might lead to potential manufacturing and cost savings in the commonality between the aircraft.

A more specific study should be conducted on multiple turnoffs and other runway configurations which could facilitate savings in ground maneuver time. This could be conducted along with the derivation of an optimum field length capability for the aircraft.

In the area of federal regulatory policy, the Part 298 exemption definitions should be examined with respect to creation of a new class of service appropriate for air travel to small communities. The fare structure also should be examined as a part of the total problem of providing air service to this market with or without federal subsidy. Criteria should be established for commuter operators to provide service on certificated routes.

The whole concept of redefining the market and creation of a new class of service creates the necessity of studying in some detail the institutional and regulatory changes which would be needed to develop and implement an air transportation system to serve small communities.

8.0 REFERENCES

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3. "Study of Short-Haul Aircraft Operating Economics", Douglas Aircraft Company for the National Aeronautics and Space Administration, Contract NAS2-8549, Moffett Field, California 94035, 1975; NASA CR-137685, Vol. I; CR-137686, Vol. II.

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9.0 APPENDICES

APPENDIX A-1

GROUND RULES FOR DERIVATION OF LOWER DENSITY TRAFFIC MODEL FOR AIR SERVICE TO SMALL COMMUNITIES

The basic data were contained in a commercial aircraft operations tape data base. The data were derived from August 1974 airline schedules and converted to daily operational levels. For the lower density network, the tape data is by local service regional airlines and domestic trunk airlines and sorted as follows:

<u>Local Service</u>

RW - Hughes Airwest
AL - Allegheny Airlines
NC - North Central Airlines
OZ - Ozark Airlines
PI - Piedmont Airlines
SO - Southern Airlines
TT - Texas International
NE - Air New England

<u>Domestic Trunk</u>

AA - American Airlines
BN - Braniff International Airways
CO - Continental Airlines
DL - Delta Airlines
EA - Eastern Airlines
NA - National Airlines
NW - Northwest Airlines
TW - Trans World Airlines
UA - United Airlines
WA - Western Airlines

o Thirty-two commuter airlines are included. These are identified in Appendix A-2, "Survey of Commuter Airlines". These are carriers which operate aircraft of 15 to 44 seats capacity. They represent a substantial fraction of the lower density model.

- These airlines provide service with the following aircraft: Beech 99, Convair Propeller, Convair 440, DC-3, deHavilland Twin Otter, deHavilland Heron, and Swearingen Metroliner.

- For all of the airlines included in the traffic model, 40 major hub airports were identified in the major hub cities of the U.S., these included SEA (Seattle), SFO (San Francisco), OAK (Oakland), LAX and BUR (Los Angeles area) on the West Coast to BOS (Boston), JFK, LGA and EWR (New York-Newark), PHL and PNE (Philadelphia), DCA (Washington, D.C.), BAL (Baltimore) to MIA (Miami) on the East Coast.

- The airline scheduled service was divided into the following service classes within the traffic model.
  - Class 1 was all commuter service to and from the major hub airports.
  - Class 2 was all non-hub commuter service.
  - Class 3 was all regional and trunk carrier service to and from the major hub airports.
  - Class 4 was all non-hub regional and trunk service.

- Passenger data was generated as Revenue Passenger Miles by applying a system load factor to seats scheduled by each airline (number of flights scheduled times seat capacity of aircraft). This data was annualized for the year 1974 as a base. Load factors were applied by service class as follows:

Classes 1 and 3	-	65 percent
Class 2	-	30 percent
Class 4	-	50 percent

These factor numbers were chosen as representative of typical load factors experienced by airlines in the 1970's on short-haul routes to and from major-hub and non-hub city airports.

- The seats-scheduled and seats-filled data grown from 1974 to 1985 at the following rates:

  - Service Classes 3 and 4 at 5 percent per year compounded.
  - Commuter Classes 1 and 2 at 2 percent per year.

  To preserve the identity of the traffic model as a lower density model, all airport pair data were excluded which exceeded 300 seats - filled per day in 1985.

- The airport-pair data were aggregated by service Class 1 through 4 into statistical elements or groups. These were grouped into 50 mile increments for simulation and evaluation at the 1985 forecasted traffic levels.

APPENDIX A-2

SURVEY OF COMMUTER AIRLINES

A CAB publication "Commuter Air Carrier Traffic Statistics Year Ended December 31, 1973" contains summary data on registered commuter airlines. Table 5 of this document lists the top 50 commuter airlines in order of passenger miles. The following comments apply with respect to the traffic model for the low density study:

1. The traffic model includes 29 of these carriers.
2. Excluded are six carriers with operations in Alaska, the Caribbean, and Hawaii.
3. Excluded are six carriers which operate aircraft with less than 15 seats.
4. Four of the airlines were excluded as not being listed in the August 1974 OAG.
5. Five airlines with daily scheduled seat miles of 301,636 and aircraft of 15 seats capacity were unintentionally omitted from the original listing.

The traffic model, in addition to the 29 commuter airlines mentioned above, contains twelve airlines operating aircraft of fifteen or more seats, but not in the top fifty CAB listing. Eight of the commuters have joint schedules published with regional airlines, and one of the 1973 commuters, Air New England, in 1974 became a certified regional airline. This latter is included in the regional airline data in the traffic model.

The exclusion of some 300,000 daily seat miles (Item 5 above) contrasts with the total of 1,968,000 which is included.

The total magnitude of commuter operations is illustrated in the following statistics quoted from a report by the Commuter Airline Association division of the National Air Transportation Association:

	1970	1971	1972	1973
Passengers (millions)	4.3	4.7	5.2	5.9

This represents an annual growth rate of about 12.5 percent.[1]

Data from the CAB[2] shows the following:

	1972	1973	%
Passengers	5,261,648	5,687,614	8.1
Passenger Miles	528,143,559	575,809,567	9.1

These data are not exactly the same, probably because of differenes in reporting schedules. However, they are in close agreement. If the CAB data were projected to 1974 at the same percent increases as 1972 to 1973, the passengers would total about 6.15 million, and passenger miles about 627.6 million. Table A-1 contains the 32 commuter airlines data which was included in the lower density traffic model. If the daily seat mile data were converted to annual, these 32 carriers provided some 718,409,425 seat miles in 1974. This represents a substantial amount of potential traffic for investigation of the commuter share of service to small communities.

(1) Aviation Daily, August 8, 1974, page 222.
(2) CAB op.cit.p.1.

TABLE A-1

SUMMARY OF DATA ON COMMUTER AIRLINES

August 1974

OAG Code	Airline	No. A/P Pairs	Equipment (Seats)	Average Departures Per Day	Average Distance (Mile)	Daily Seat Miles
AG	Air Sunshine	4	DC-3 (26)	13.43	80	27,857
AK	Altair Airlines, Inc.	23	B-99 (15)	84.43	97	122,640
CB	Commuter Airlines	6	SWM (18)	14.14	186	47,456
DD	Command Airways	5	DTO (15)	23.43	77	26,970
		7	B-99 (15)	18.86	133	37,556
DN	Skystream	15	B-99 (15)	46.57	137	95,492
EP	Aspen Airways	1	CVR (43)	10.0	114	49,020
FE	Florida Airline	11	DC-3 (26)	51.0	64	84,838
FS	Sun Valley Key	4	DTO (17)	17.0	152	43,843
FY	Metroflight Airlines	4	DTO (17)	60.57	48	49,800
GM	Scheduled Skyways	1	B-99 (15)	7.14	141	15,107
GW	Golden West Airlines	16	DTO (17)	158.57	41	111,792
HI	Hawkeye Airlines, Inc.	4	DC-3 (26)	12.57	82	26,802
HU	Cascade Airways	16	B-99 (15)	46.43	114	79,151
HY	Houston Metro Airlines	7	DTO (17)	96.14	54	88,730
IU	Midstate Air Commuter	18	B-99 (15)	56.86	91	77,563
JC	Rocky Mountain Airways	8	DTO (19)	42.0	90	72,086
KQ	Air South, Inc.	7	B-99 (15)	19.86	138	41,147
		5	F-27 (40)	18.86	151	113,754
PM	Pilgrim Airlines	17	DTO (18)	66.29	83	99,563
PT	Provincetown - Boston Airline	2	DC-3 (32)	12.0	116	44,352
SG	Shorter Airlines, Inc.	4	DC-3 (26)	10.29	161	43,034
SL	Southeast Airlines, Inc.	3	MR4 (44)	12.43	98	53,328

SUMMARY OF DATA ON COMMUTER AIRLINES (Continued)

OAG Code	Airline	No. A/P Pairs	Equipment (Seats)	Average Departures Per Day	Average Distance (Mile)	Daily Seat Miles
SS	Shawnee Airlines, Inc.	8	DC-3 (26)	25.43	117	77,250
SZ	Sierra Pacific Airlines	3	CV4 (43)	10.0	159	68,284
TJ	Air Idaho, Inc.	5	HRN (16)	13.0	124	25,728
UQ	Suburban Airlines, Inc.	3	DTO (19)	9.71	68	12,594
WR	Air Speed, Inc.	3	B-99 (15)	9.29	103	14,314
WQ	Flightways Corp.	1	HRN (16)	8.86	94	13,321
XV	Mississippi Valley Airways, Inc.	6 5	DTO (16) SWM (18)	20.0 10.57	104 136	33,225 25,833
YR	Scenic Airlines, Inc.	2	DTO (17)	4.57	179	13,921
ZB	Midwest Commuter Airlines	3	B-99 (15)	9.29	117	16,307
ZV	Air Midwest	12	B-99 (15)	44.0	84	55,138
ZW	Air Wisconsin	13	SWM (18)	89.14	100	161,079
	TOTALS	252				1,968,245

The above commuter airlines include all those which operate aircraft between 15 and 44 seats passenger capacity. These are considered as operators who by 1980-1985 would be suitable for an aircraft of at least 30 seats capacity.

This data was based upon published schedules for August 1974. All of the above carriers operating aircraft in excess of 30 seats operate under the Federal Regulations, Part 298, Title 14, Aeronautics and Space as exempted carriers, with the exception of Aspen Airways which is a CAB certificated carrier.

APPENDIX A-3

SURVEY OF AIRPORTS USED BY COMMUTER AIRLINES

A survey was conducted to ascertain runway lengths of airports used by the 32 commuter airlines in the market. A total of 142 airports were included, of which 127 had runways of 4,500 feet length or longer. The remaining 15 airports had runways varying in length from 3,100 feet to 4,400 feet as shown in the accompanying Table A-2.

TABLE A-2

MAJOR COMMUTER AIRLINES

AIRPORTS WITH SHORT RUNWAYS

Code	City	Airport	Maximum Runway Length (Less Than 4500 Ft)	Flights/Day
ASX	Ashland, Wi	J.F.K. Memorial Airport	3,600	1
AUX	Wausau, Wi	Municipal Airport	4,400	4
CGX	Chicago, Il	Merrill C. Meigs Field	3,950	14
CIB	Catalina Is., Ca	Catalina	3,250	18
CLC	Clear Lake City, Tx	Clear Lake Metroport	2,500	24
DVN	Davenport, Ia	Davenport Airport	4,000	0*
EGV	Eagle River, Wi	Eagle River Municipal	3,600	0
FUL	Fullerton, Ca	Fullerton Airport	3,100	25
HDN	Steamboat Springs, Co	Steamboat Springs Municipal	3,300	11
HFD	Hartford, Ct	Hartford-Brainard Airport	4,400	0
HHH	Hilton Head Is., SC	Hilton Head	4,300	5
OJC	Olathe, Ks	Johnson County Airport	4,100	8
OKK	Kokomo, In	Kokomo Airport	4,000	3
PLY	Plymouth, In	Plymouth Municipal	3,550	1
SUE	Sturgeon Bay, Wi	Door County-Cherryland Airport	3,600	3

*Weekly schedules less than 5 listed as zero.

APPENDIX A-4

DIRECT OPERATING COST MODIFICATIONS

The basic trip direct operating cost equations used in this study were modified from the original Medium Density Study. For example, Flight Crew Costs were computed with an equation drawn from the NASA Short-Haul Economic Study (NASA CR-137685, Contract NAS2-8549). This equation reflected actual regional airline experience at 1973 levels. The equation used is as follows:

Flight Crew Expense in \$ per Block Hour

$$FCE = K_L \left[27.97 + 0.18 \left(\frac{TOGW}{1000} + V_{CR}\right)\right]$$

where

K_L = 1.207 (an inflation factor)

TOGW = gross takeoff weight of aircraft

V_{CR} = design cruise speed in miles per hour

This equation was used for the 30-passenger turbofan study aircraft, the SD3-30, the Falcon 30 and the DHC-7.

A second variation was to use the Short-Haul Economic Study equation for Insurance and Depreciation. For the insurance expense the equation was:

$$\text{Insurance} = \frac{\text{Unit Cost x Rate}}{\text{Annual Utilization}}$$

For the SD3-30, the Falcon 30, and the DHC-7, the rate was 1.5 percent and annual utilization was 2,500 hours.

Depreciation was computed as

$$\text{Cost} = \frac{\text{(Spares Factor) (Unit Cost) (1-Residual)}}{\text{(Depreciation Period) (Annual Utilization)}}$$

For the three competitive aircraft above, the spares factor was 1.12, the residual value was 15 percent, the depreciation period was ten years and annual utilization was 2,500 hours.

For the study turbofan and turboprop 30-passenger aircraft, insurance was assumed at 1 percent per year, spares at 10 percent, annual utilization at 2,800 hours, and depreciation over fifteen years. The slightly reduced levels for spares and insurance for the study aircraft are based upon an assumption of an initial design policy to produce a superior aircraft. This results in an extended lifetime with less requirement for spares replacement. The slightly greater utilization level reflects the greater speed of both the study turbofan and turboprop aircraft compared with the competitive configurations.

A third area of trip cost adjustment was in airframe and engine maintenance. Actual data on airframe and engine maintenance were obtained for the DHC-6 aircraft for 1973. The source was CAB data used in the Short-Haul Study cited above. The SD3-30 and DHC-7 both use versions of the same basic engine as the DHC-6. Therefore, the engine maintenance was assumed the same per engine as the DHC-6, except for an inflation factor. The engine maintenance costs were inflated by 1.207 for labor and 1.398 for materials from the 1973 levels. Airframe maintenance similarly was adjusted from the DHC-6 level for 1973. This included the propeller in the airframe maintenance costs.

These airframe maintenance costs assume that propeller maintenance in the DHC-7 and SD3-30 is less costly than the aircraft of the 1970-73 time period due to technology improvements.

These costs per flight hour were converted to equations of the form a + bR. The trip costs as a function of range thus were:

Cost/Trip (SD3-30) = $39.83 + $1.713 R with R in nautical miles, and

Cost/Trip (DHC-7) = $57.13 + $2.181 R

The Falcon 30 trip cost equation was derived in similar fashion. The equation used was:

Trip Cost = $73.15 + $1.325 R

Note that in all of these equations, the trip cost varies with the constant slope term. Comparison of one aircraft with another will show a constantly changing percentage relationship with range.

COMPARISON AND UTILIZATION OF MEDIUM DENSITY AND SHORT-HAUL ECONOMIC STUDY DOC EQUATIONS.

The work statement for the extended study suggested an examination of alternate DOC and IOC methods, compared with the original medium density study. The NASA Short-Haul Study (NAS2-8549) results were examined and modifications adopted as discussed herein. The Aerospace Corporation IOC formula yielded essentially the same values as the IOC method used in the study. The Aerospace Corporation IOC formula developed for rural and high-density commuter carriers is as follows:

$$\text{Cost/Departure} = \$13.44 + 1.565\ NP + .013574\ ASM + .0088004\ RPM$$

where

NP	=	number of passengers carried
ASM	=	aircraft seats times miles per trip
RPM	=	revenue passenger miles

The direct operating cost equations for the 30-passenger turbofan study aircraft were computed with both the medium density and the short-haul economic study formulas. Comparison of the DOC methods are depicted in Table A-3.

The 30-passenger turboprop study aircraft had similar characteristics to the study turbofan. It was considered to have the same general level of airframe and engine technology. Therefore, in computing the trip costs for the 30TP in the Frontier Airlines network, the medium density approach was adopted with one exception. The crew costs were computed with the standard ATA propeller crew cost formula. Trip cost computations for the average Frontier Airlines trip are shown in Table A-4. The costs are computed with both the medium density and the ATA crew costs. Comparison of the 30TF and 30TP trip costs as reported in Table 5-4 shows about a 20 percent differential. If the short-haul crew costs were used, this differential would be reduced to about 16 percent. If the medium density crew costs were used at the same level for both turbofan and turboprop aircraft, the differential would be about 8 percent in favor of the turboprop.

TABLE A-3

COMPARISON OF DOC METHODS

30-PASSENGER TURBOFAN

COST ITEMS AND TRIP DATA	ORIGINAL MEDIUM DENSITY STUDY	CURRENT SMALL COMMUNITY STUDY
Crew Cost	$149.88\ T_B$	$109.78\ T_B$
Depreciation	$51.02\ T_B$	$75.38\ T_B$
Insurance	$8.05\ T_B$	$11.88\ T_B$
Airframe Maintenance	$23.13\ T_B + 10.01$	$67.83\ T_B$
Engine Maintenance	$40.35\ T_B + 12.12$	$63.09\ T_B$
Computed Trip Data:		
Range (nautical miles)	108.5	108.5
Block Time (hours)	.466	.466
Fuel Consumption (lb/n.mi)	225 + 6.56 R	225 + 6.56 R
Fuel Cost ($)	36.36	36.36
Other DOC Costs	149.08	152.55
DOC/Trip ($) (TOTAL)	185.44	188.91
Fleet DOC at 142,000 Trips/Year	26.3	26.8
Equivalent DOC Equation	69.86 + 1.065 R	56.27 + 1.222 R

TABLE A-4

COMPARISON OF DOC METHODS

30-PASSENGER TURBOPROP

COST ITEMS AND TRIP DATA	ORIGINAL MEDIUM DENSITY STUDY	CURRENT SMALL COMMUNITY STUDY
Crew Cost	149.88 T_B (Jet)	97.21 T_B (Prop)
Depreciation	44.72 T_B	
Insurance	7.06 T_B	
Airframe Maintenance	24.16 T_B + 9.28	
Engine Maintenance	31.89 T_B + 9.49	
Computed Trip Data:		
Range (nautical miles)	108.5	
Block Time (hours)	.466	
Fuel Consumption (lb/n.mi)	229 + 5.63 R	
Fuel Cost ($)	32.45	
Other DOC Costs	138.88	114.32
DOC/Trip ($) (TOTAL)	171.33	146.77
Fleet DOC at 142,000 Trips/Year ($ Million)	24.3	21.0
Equivalent DOC Equation	73.53 + 0.901 R	62.99 + 0.772 R

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